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(12) **United States Patent**
Suzuki et al.

(10) **Patent No.: US 10,700,288 B2**
(45) **Date of Patent: Jun. 30, 2020**

(54) **LIGHT-EMITTING ELEMENT, LIGHT-EMITTING DEVICE, ELECTRONIC DEVICE, LIGHTING DEVICE, AND LIGHTING SYSTEM**

(71) Applicant: **Semiconductor Energy Laboratory Co., Ltd.**, Kanagawa-ken (JP)

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(73) Assignee: **Semiconductor Energy Laboratory Co., Ltd.** (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 495 days.

(21) Appl. No.: **15/215,117**

(22) Filed: **Jul. 20, 2016**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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Jan. 15, 2016 (JP) 2016-006140

(51) **Int. Cl.**
H01L 51/00 (2006.01)
C07D 209/86 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01L 51/0072*** (2013.01); ***C07D 209/86*** (2013.01); ***C09K 11/025*** (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

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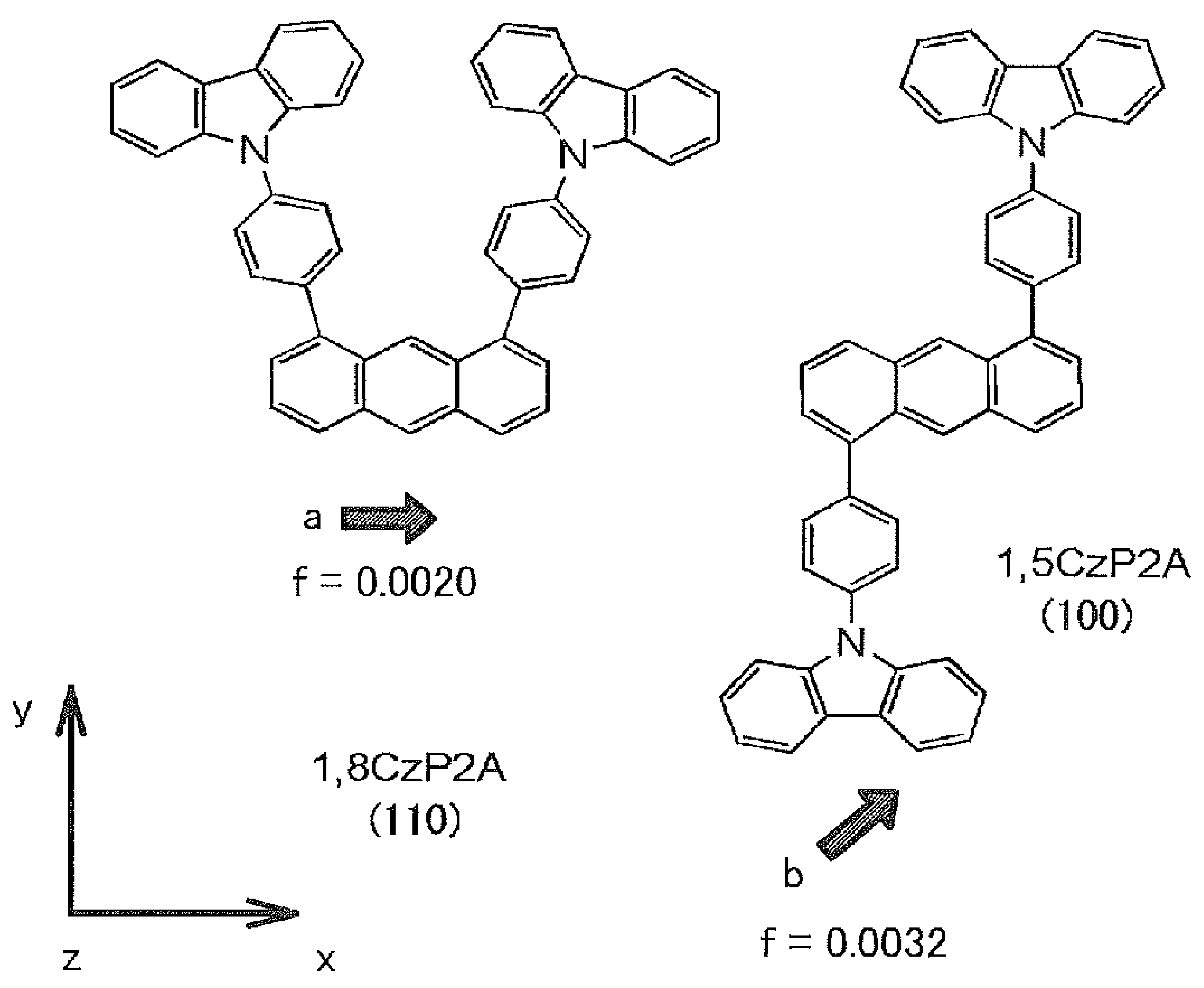
Primary Examiner — Jay Yang
(74) *Attorney, Agent, or Firm* — Husch Blackwell LLP

(57) **ABSTRACT**

A light-emitting element that contains a fluorescent compound, which has high efficiency is provided. A light-emitting element in which the proportion of delayed fluorescence to the total light emitted from the light-emitting element is higher than that in a conventional light-emitting element is provided. Emission efficiency of the light-emitting element containing a fluorescent compound can be improved by increasing the probability of TTA caused by an organic compound in an EL layer, converting energy of triplet excitons, which does not contribute to light emission, into energy of singlet excitons, and making the fluorescent compound emit light by energy transfer of the singlet excitons.

24 Claims, 36 Drawing Sheets



(51) **Int. Cl.**
C09K 11/02 (2006.01)
H01L 51/50 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 51/0052*** (2013.01); *H01L 51/5012* (2013.01); *H01L 51/5056* (2013.01); *H01L 51/5072* (2013.01)

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FIG. 1A

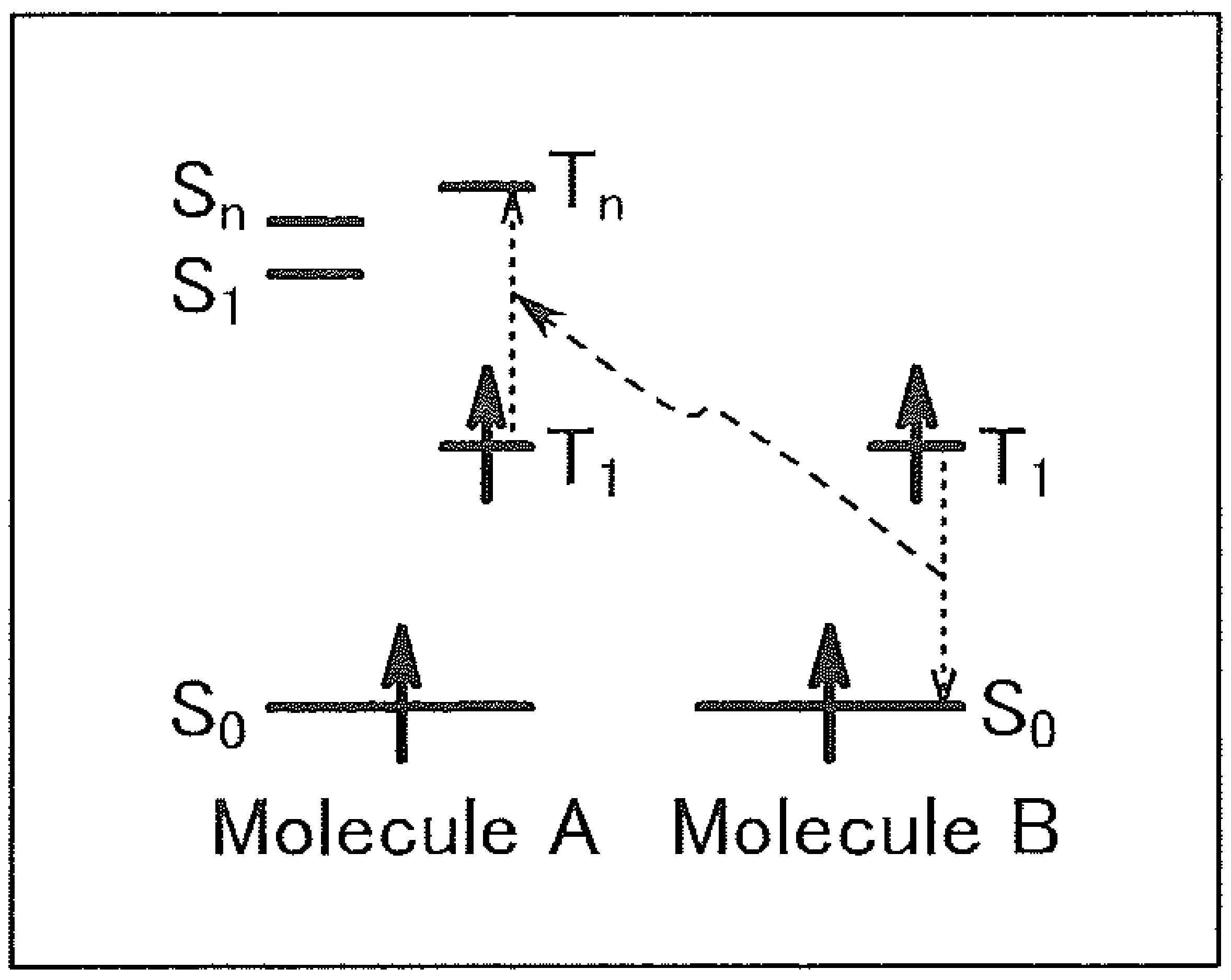


FIG. 1B

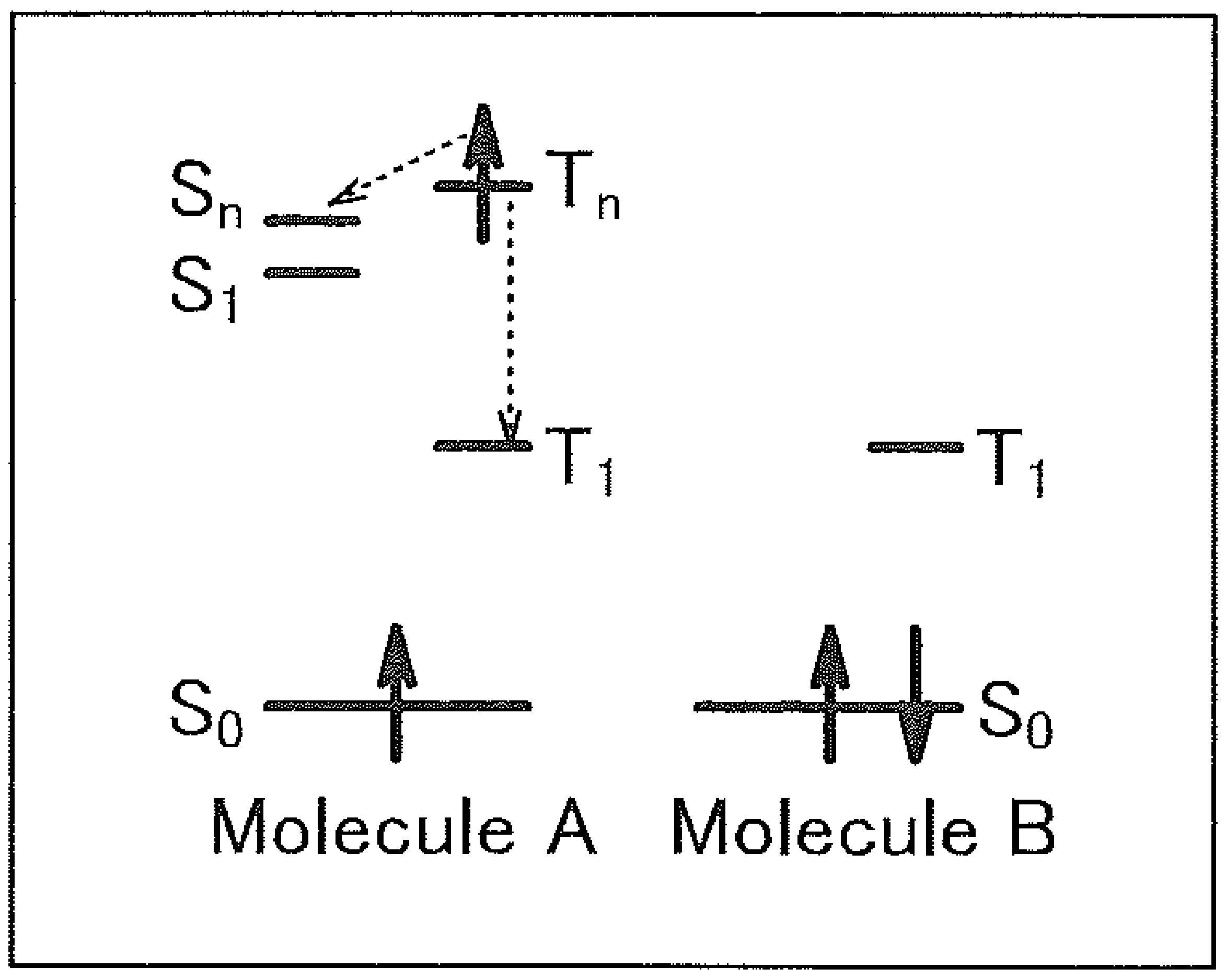


FIG. 1C

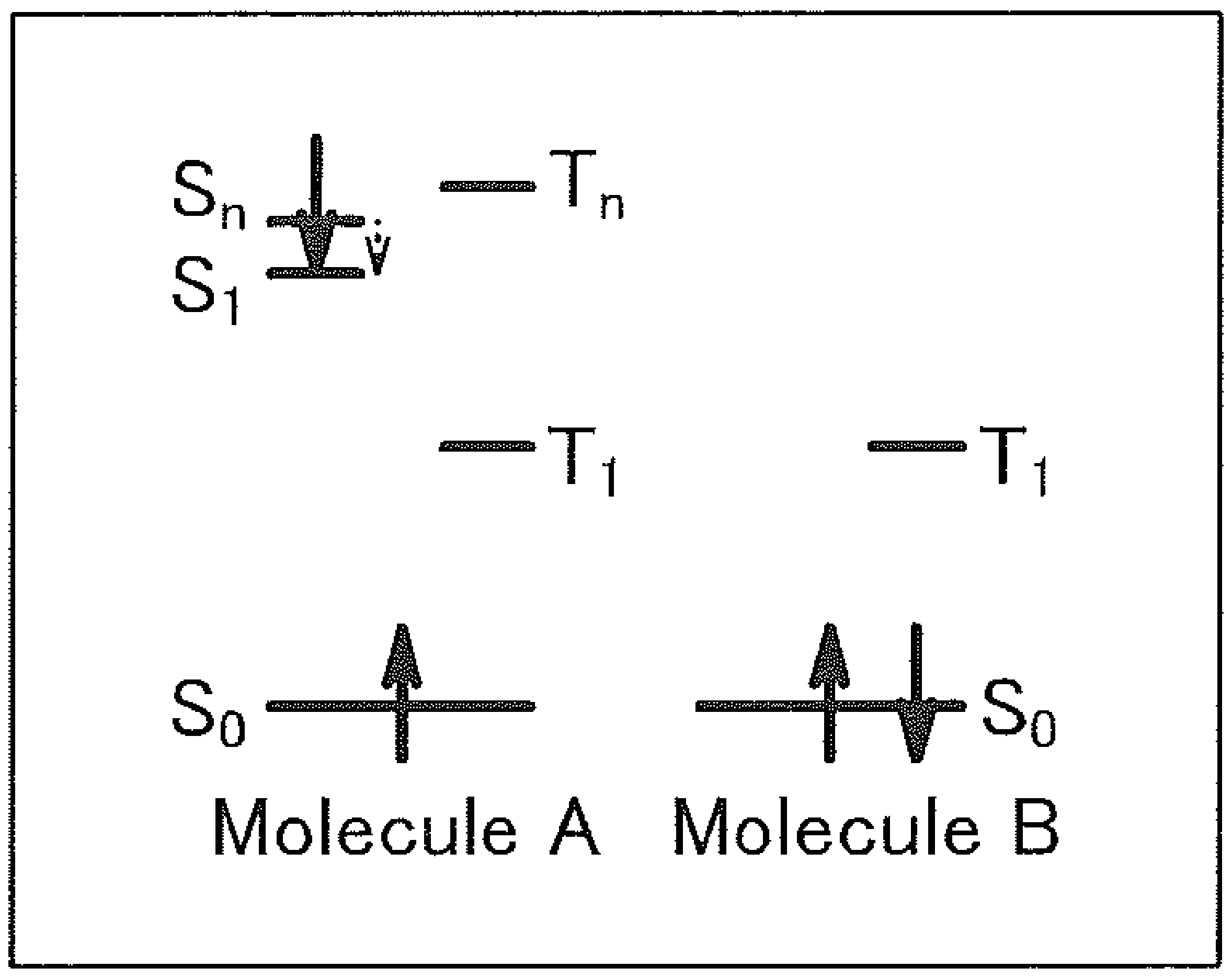


FIG. 1D

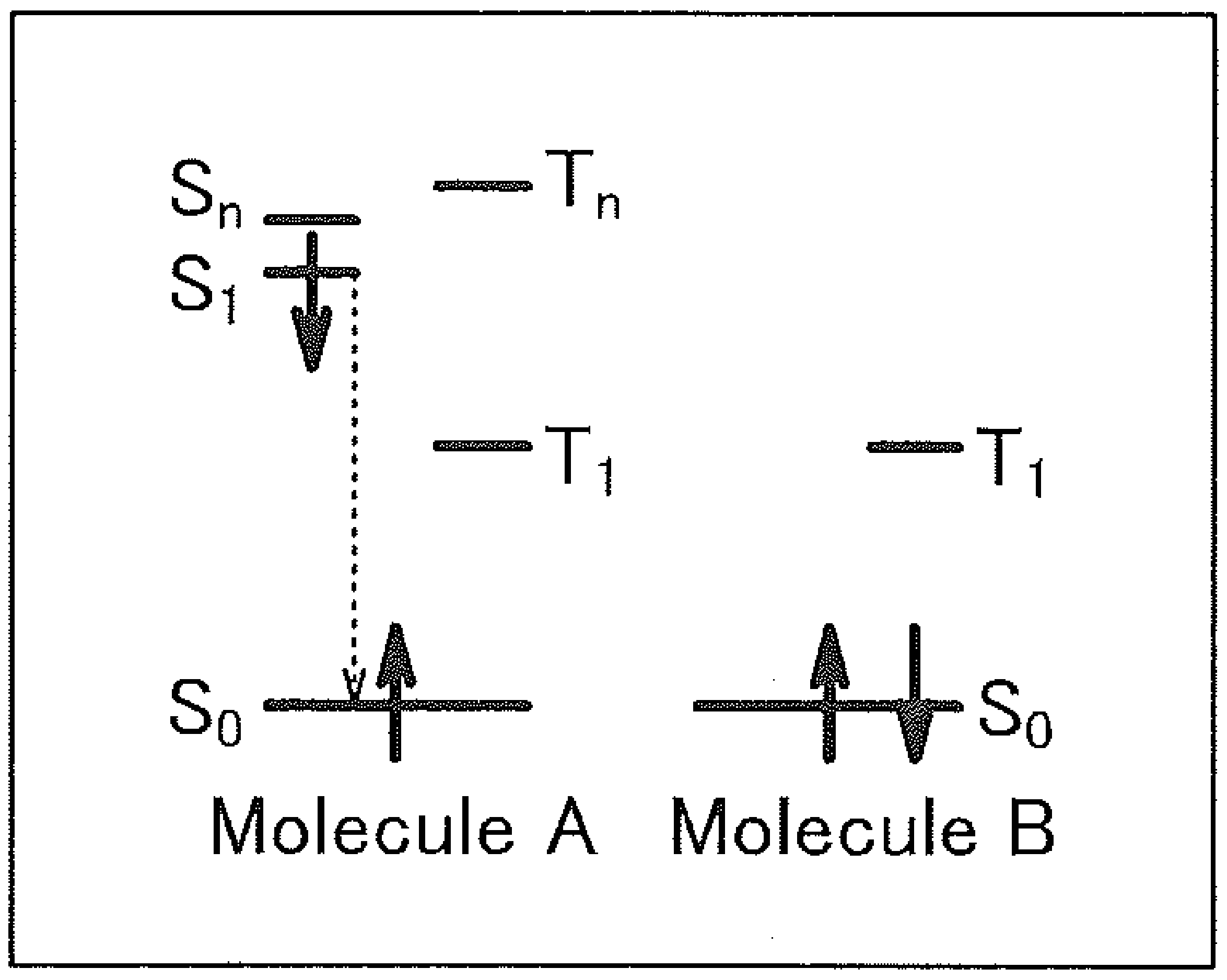


FIG. 2

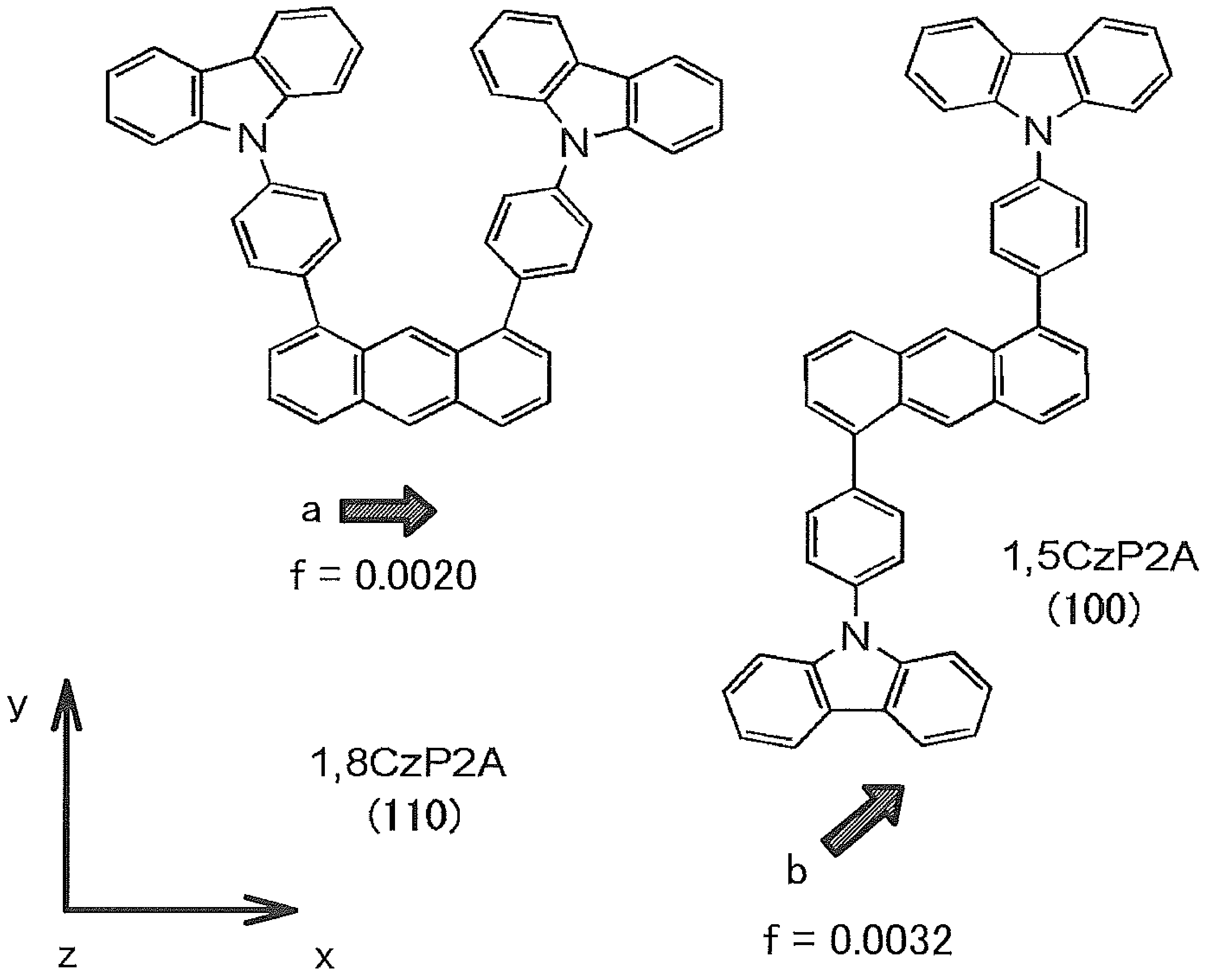


FIG. 3

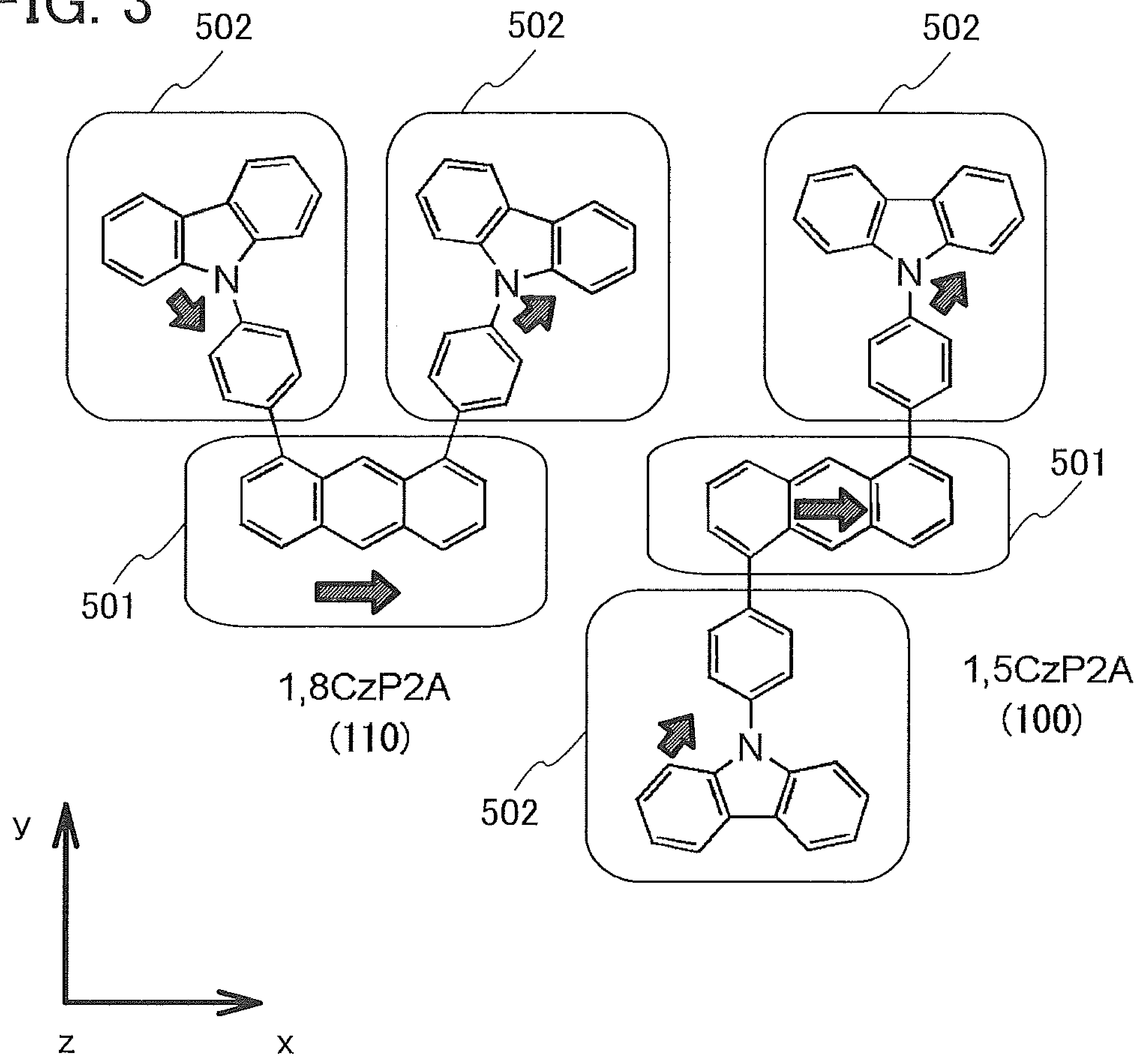
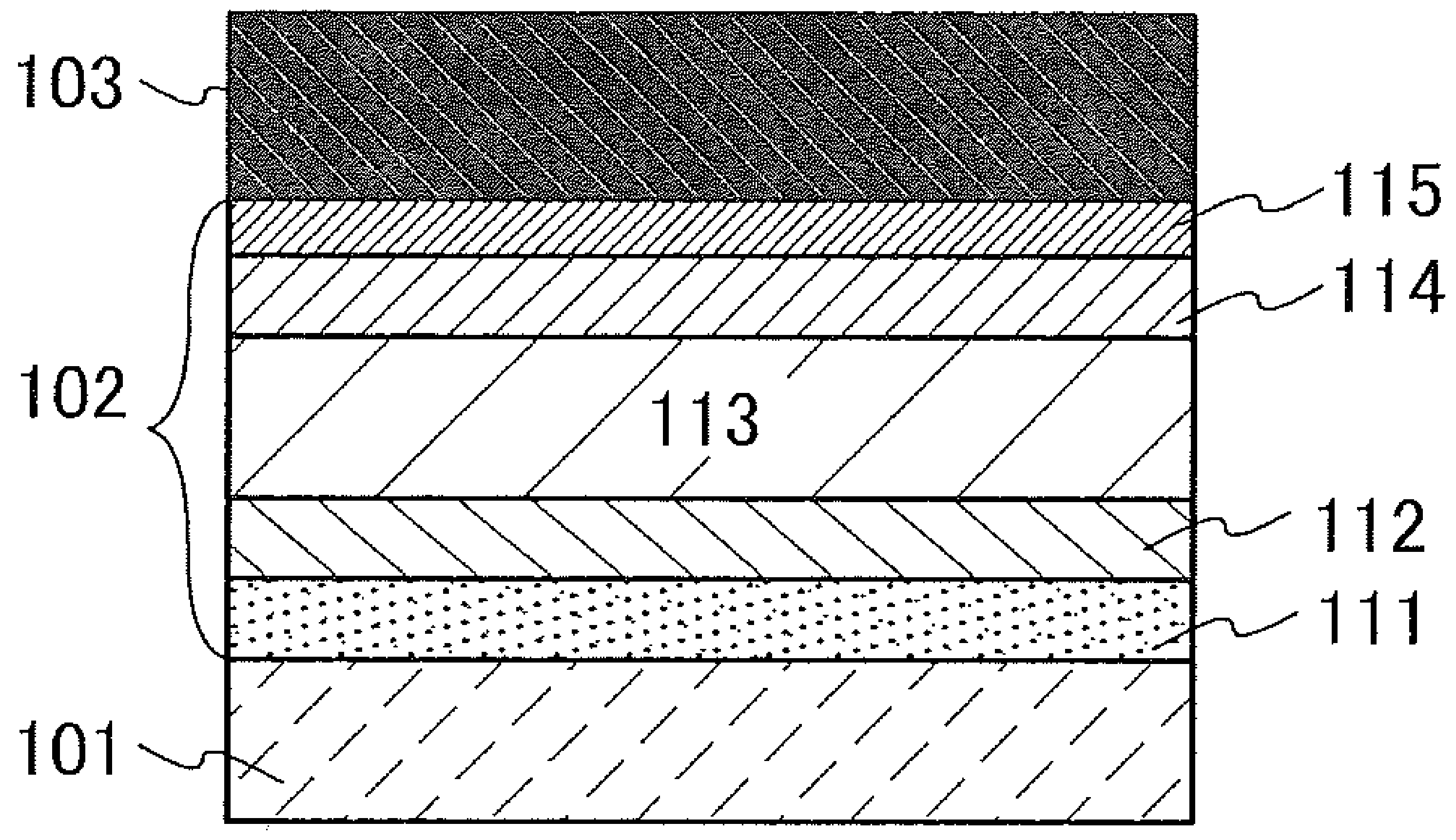


FIG. 4A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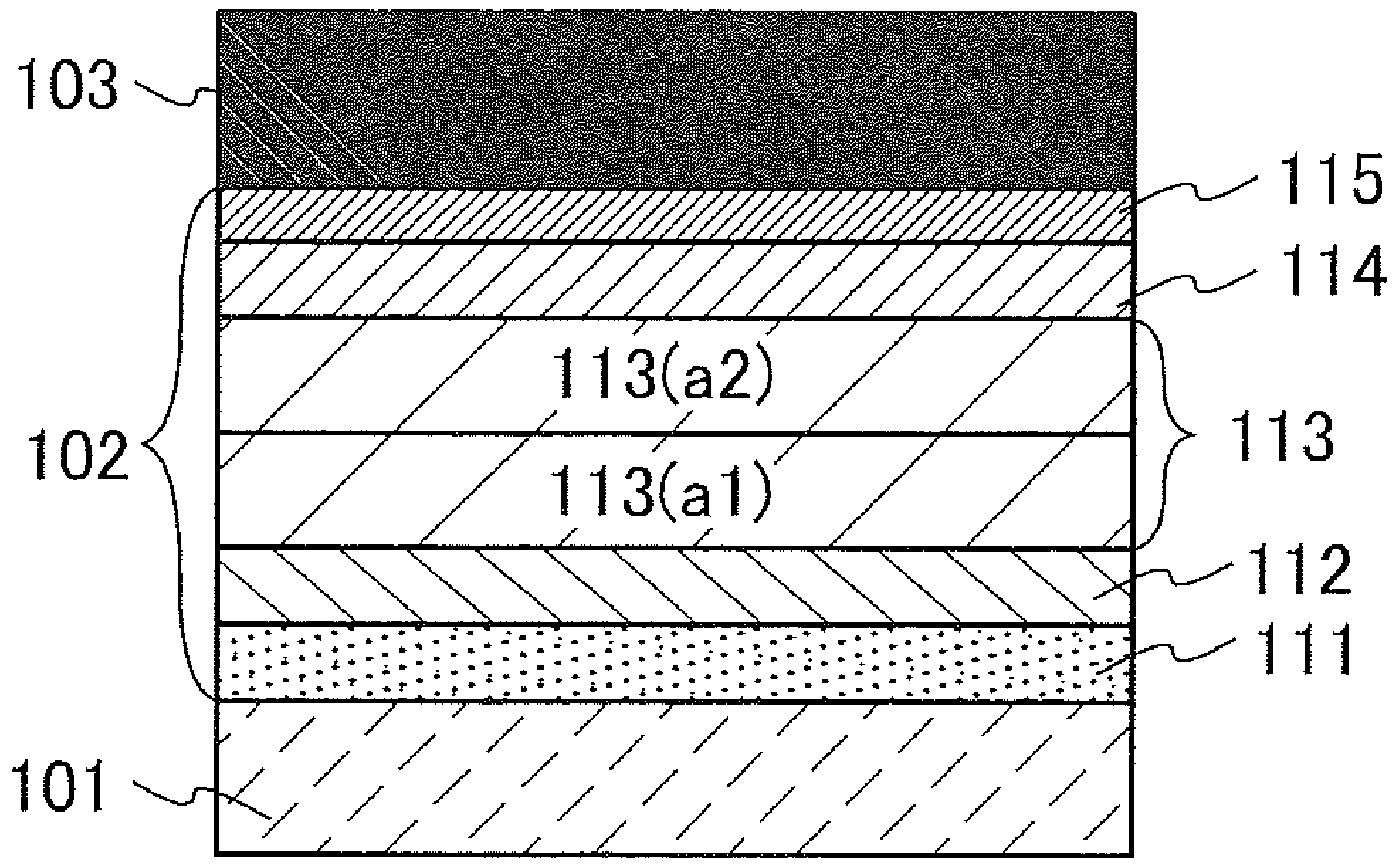
115
114
102
113
112
111
101

FIG. 4B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115
114
113(a2)
102
113(a1)
113
112
111
101

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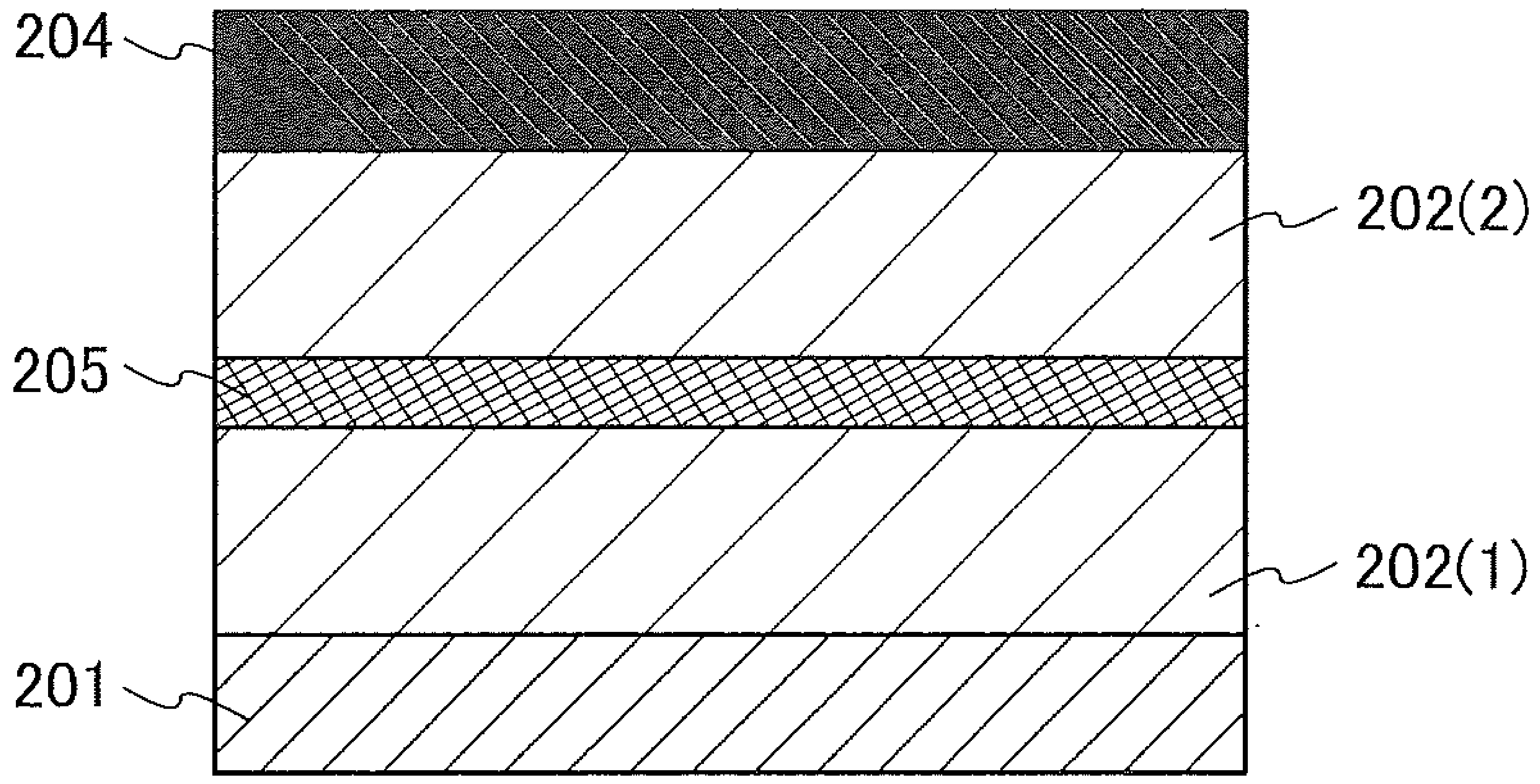
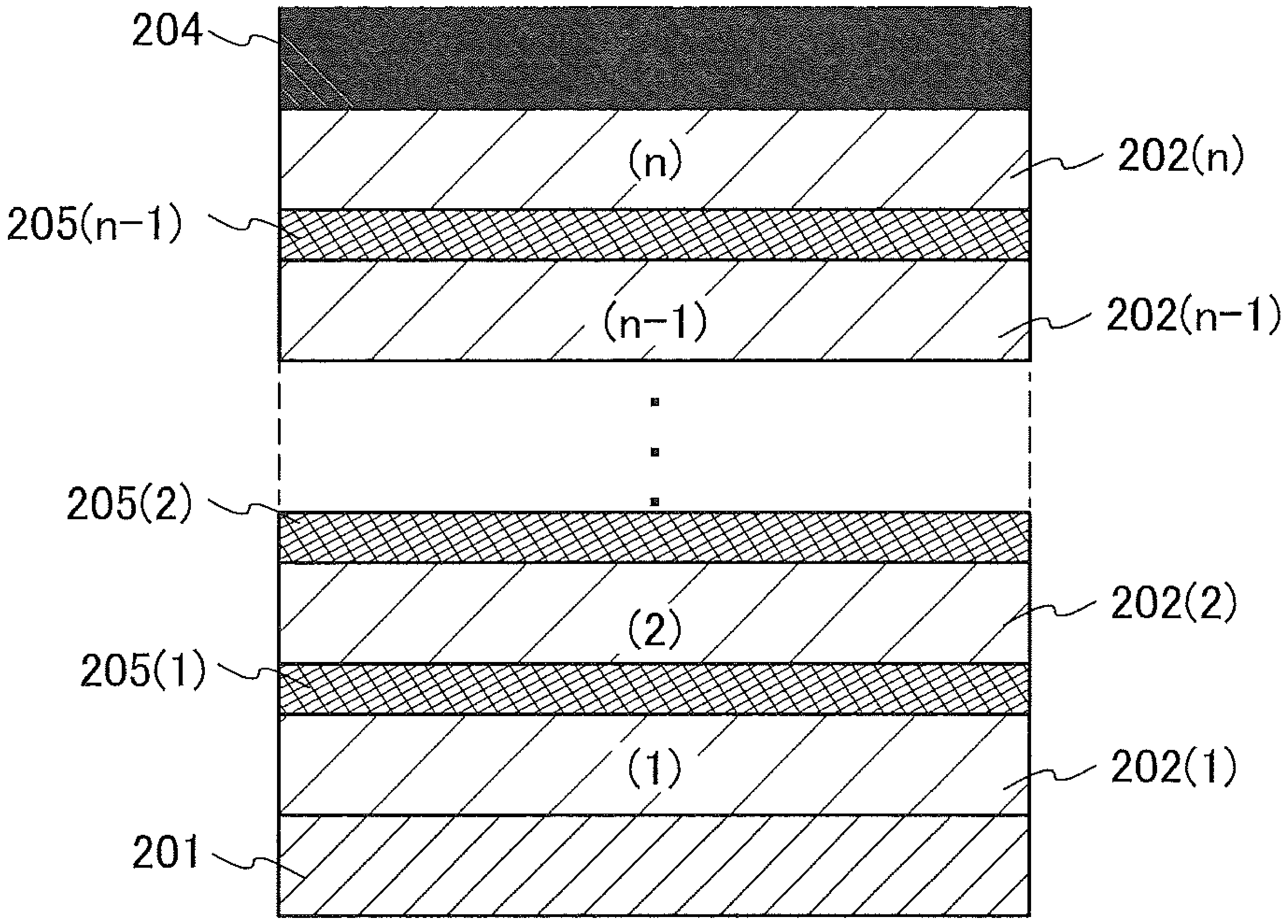

204
202(2)
205
202(1)
201

FIG. 5B


204
(n)
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(n−1)
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205(2)
(2)
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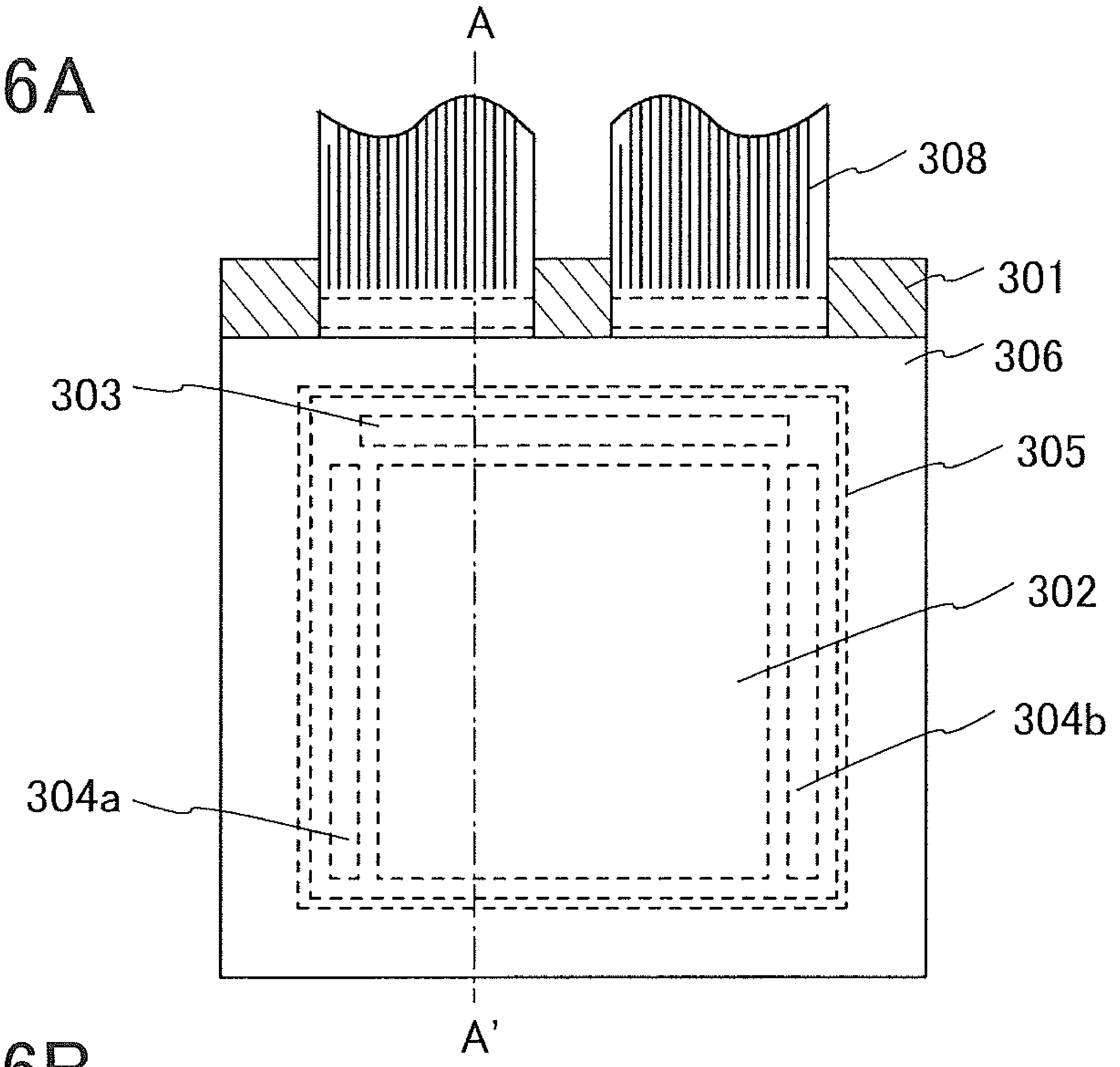
205(1)
(1)
202(1)
201

FIG. 6A



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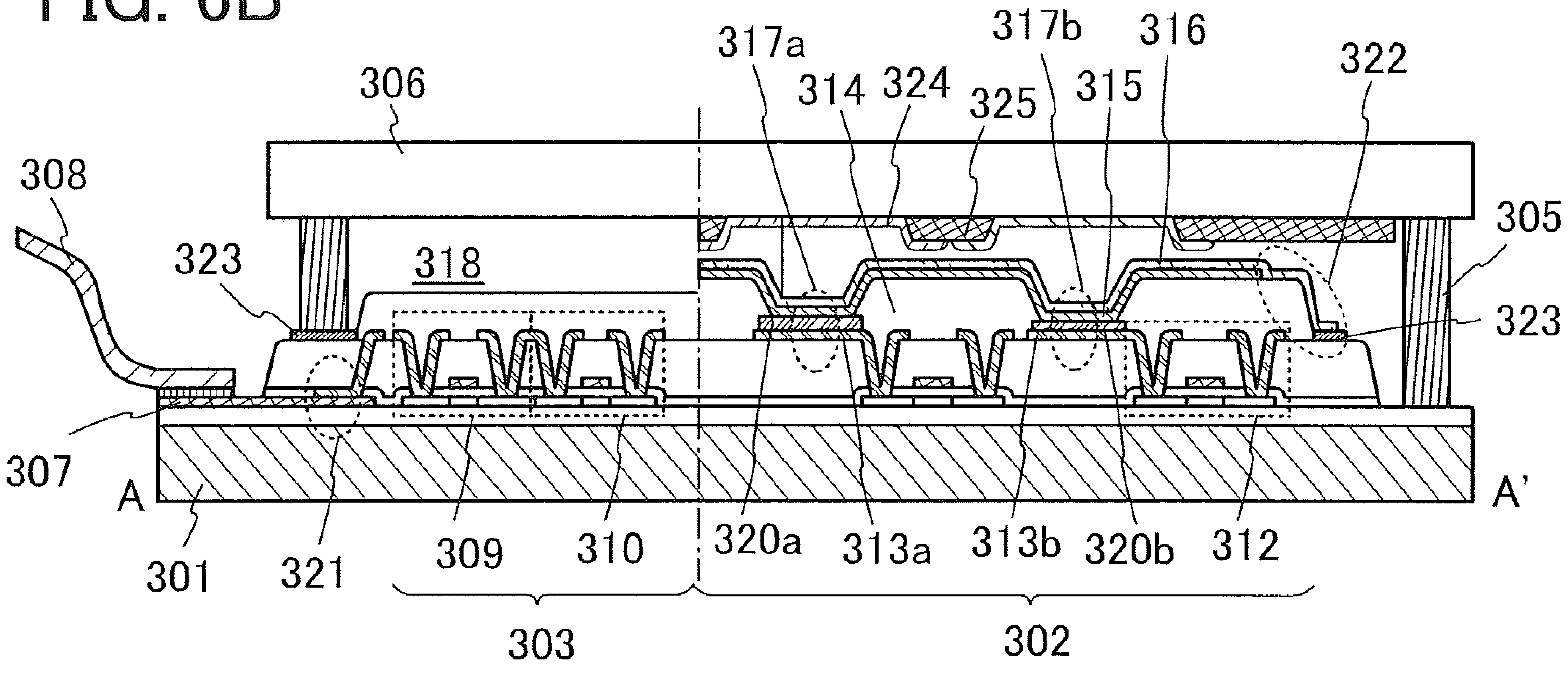
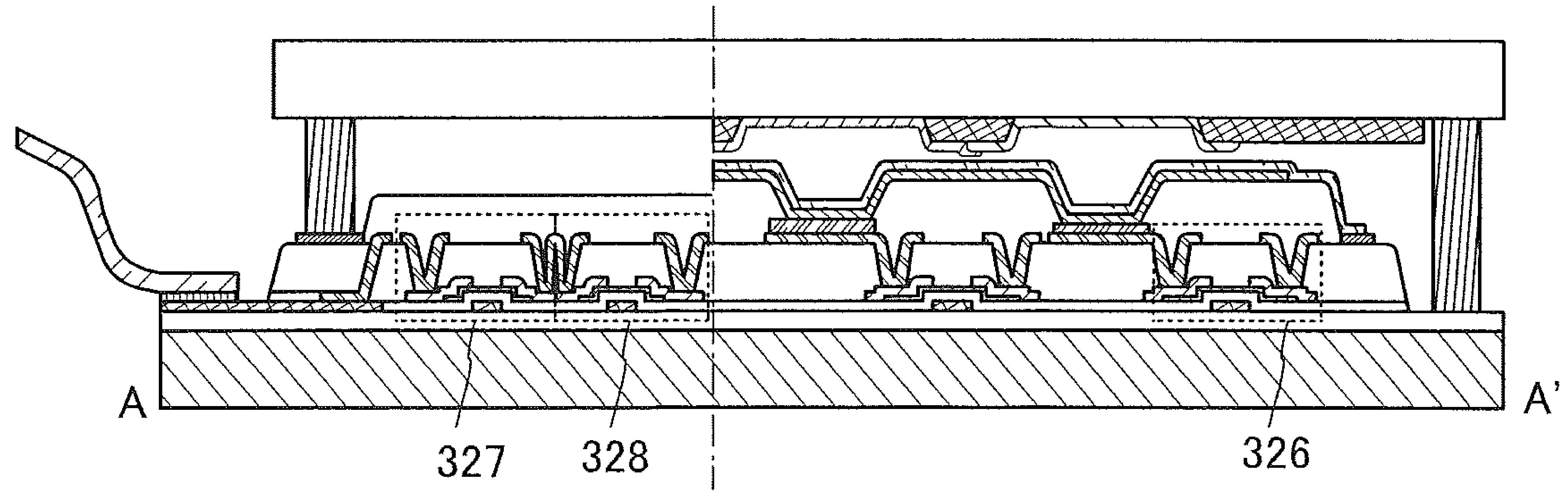


FIG. 6C



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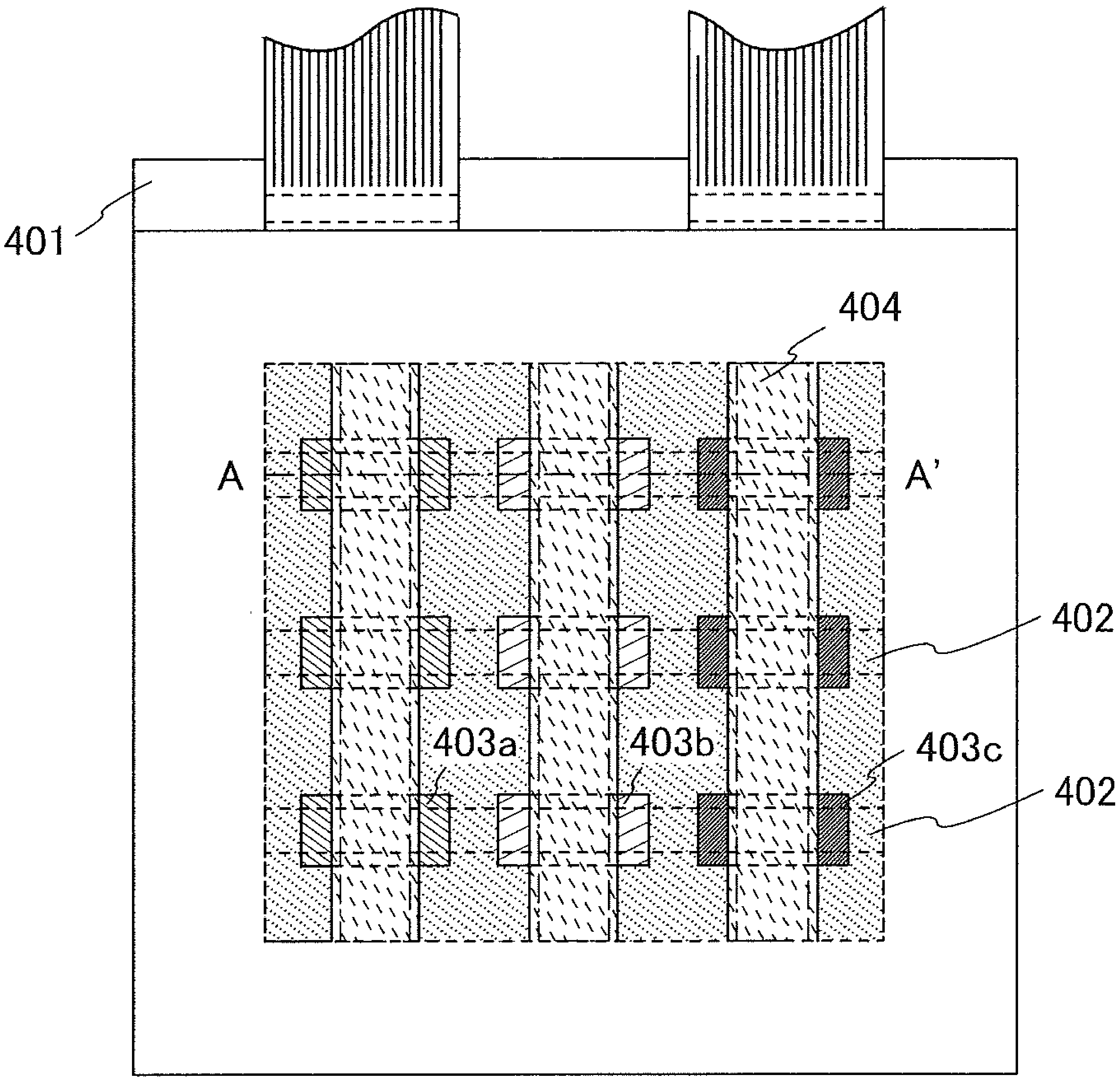
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404
A
A'
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403a
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403c
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FIG. 7B

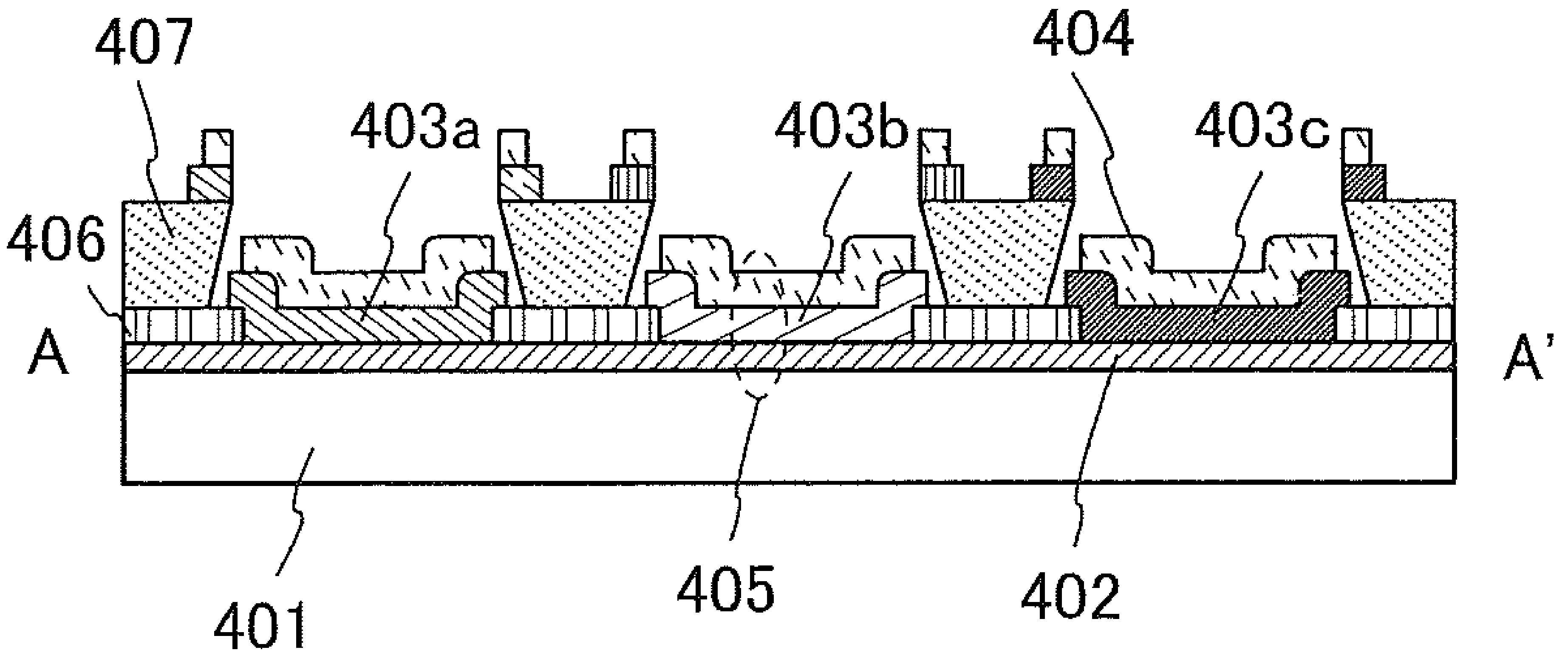
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FIG. 8A

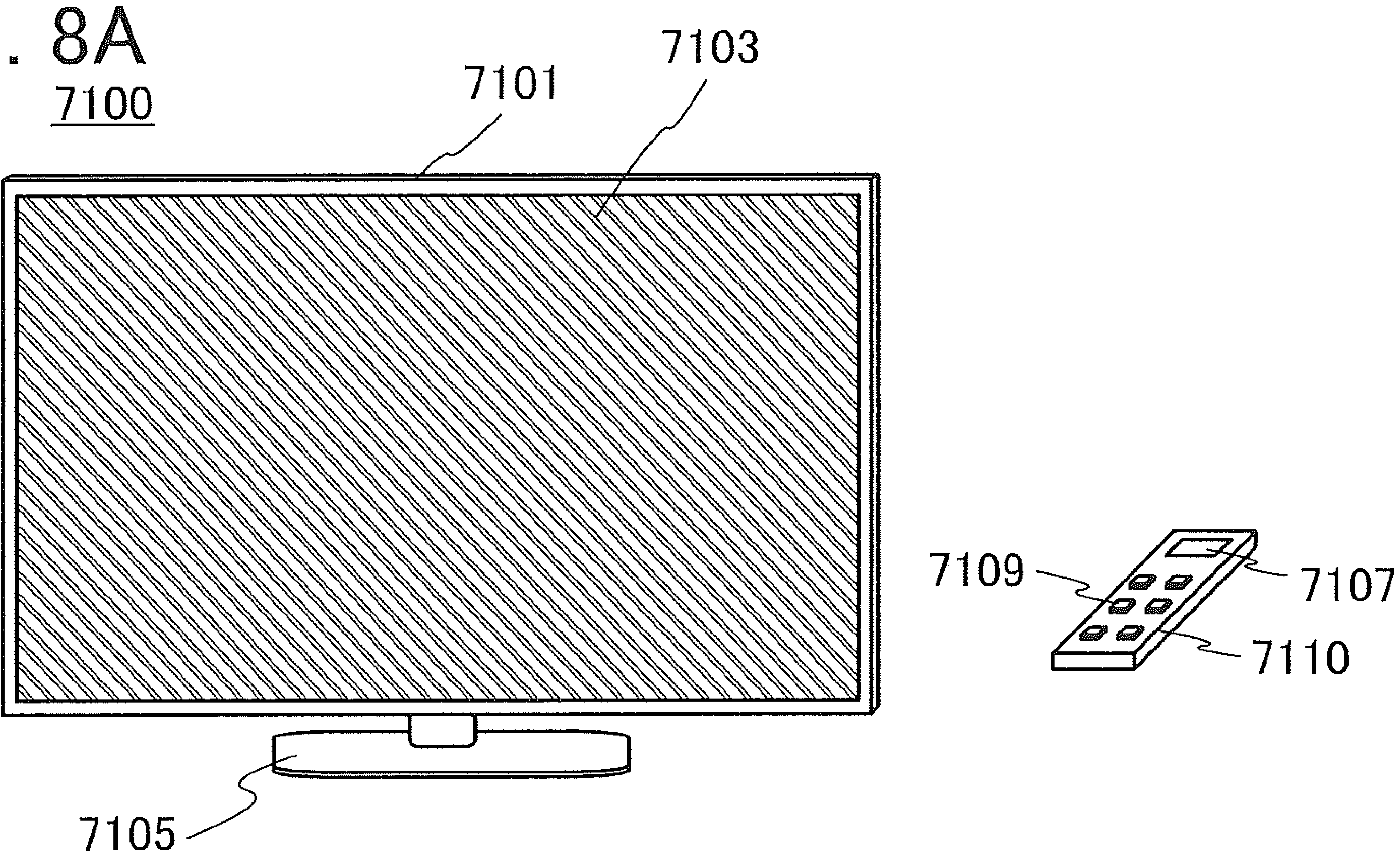


FIG. 8B

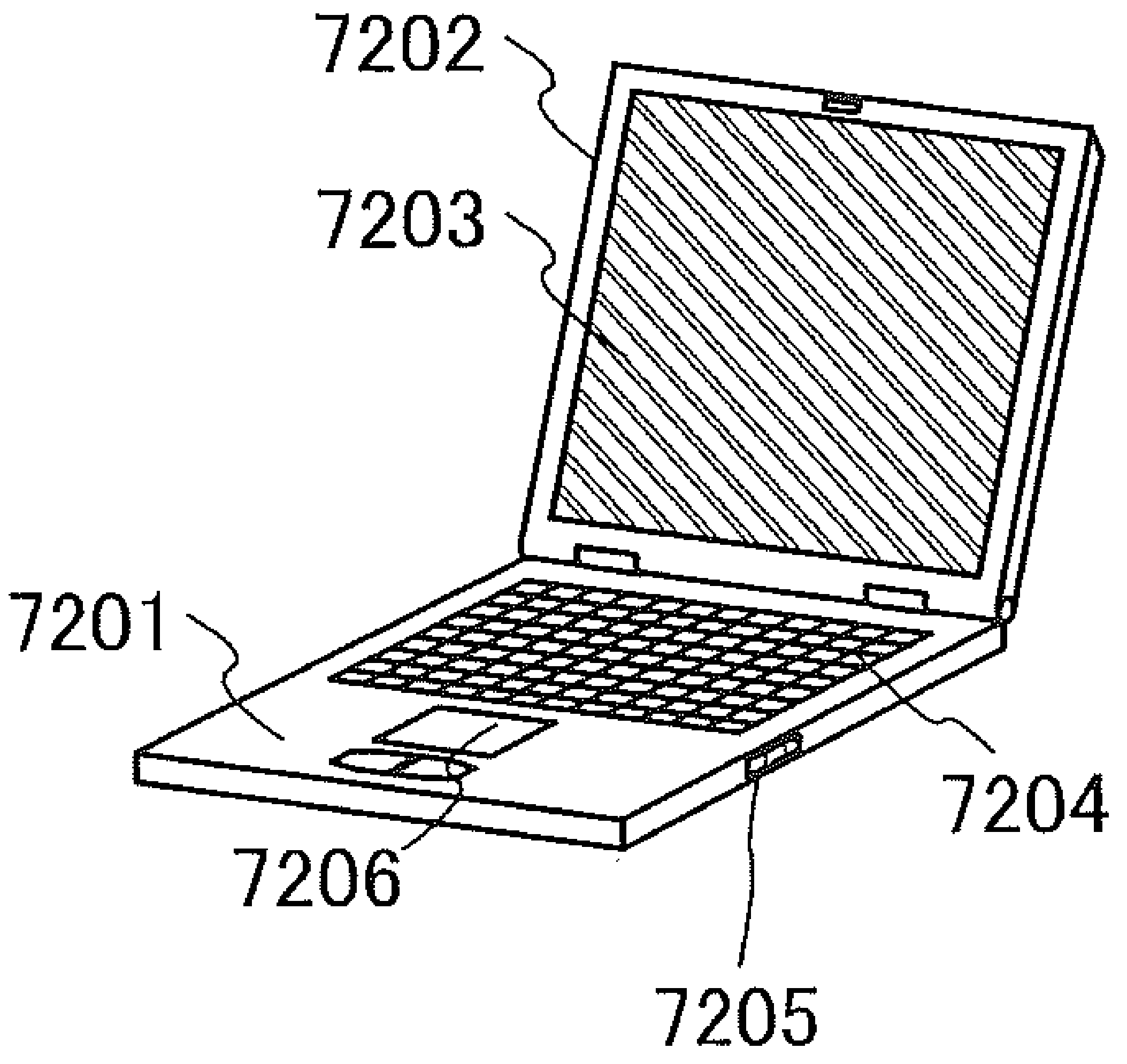


FIG. 8C

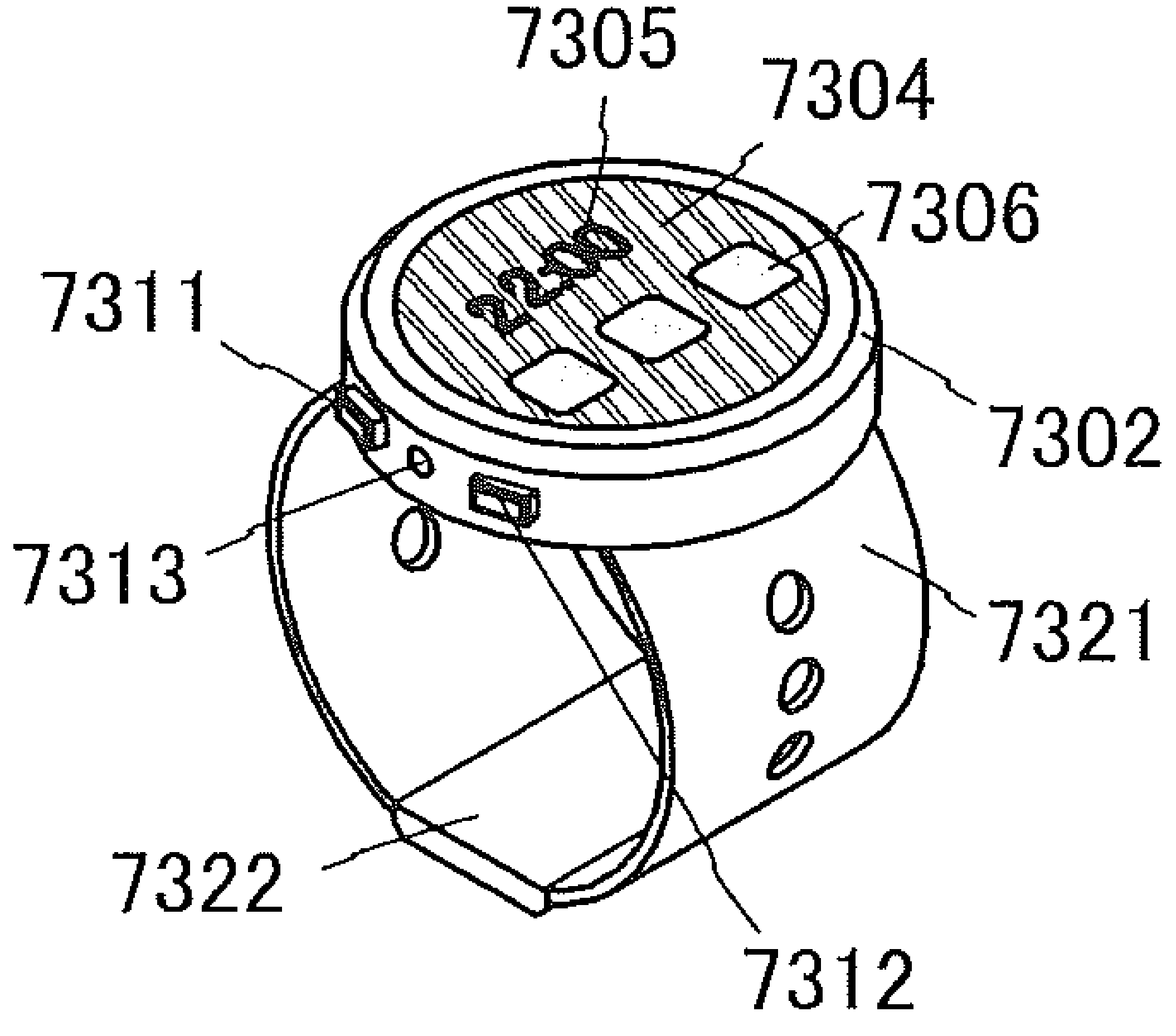


FIG. 8D

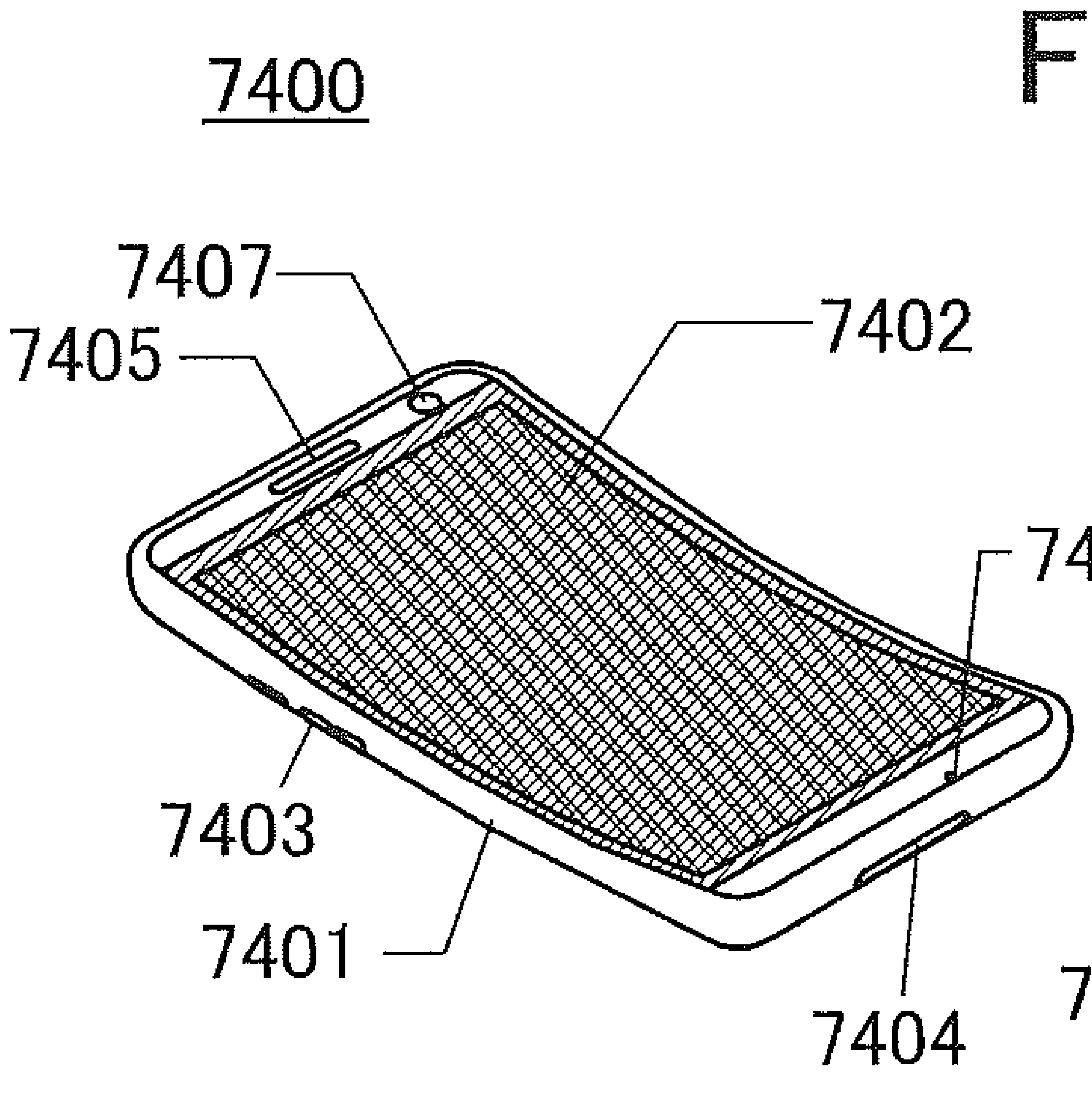


FIG. 8D'-1

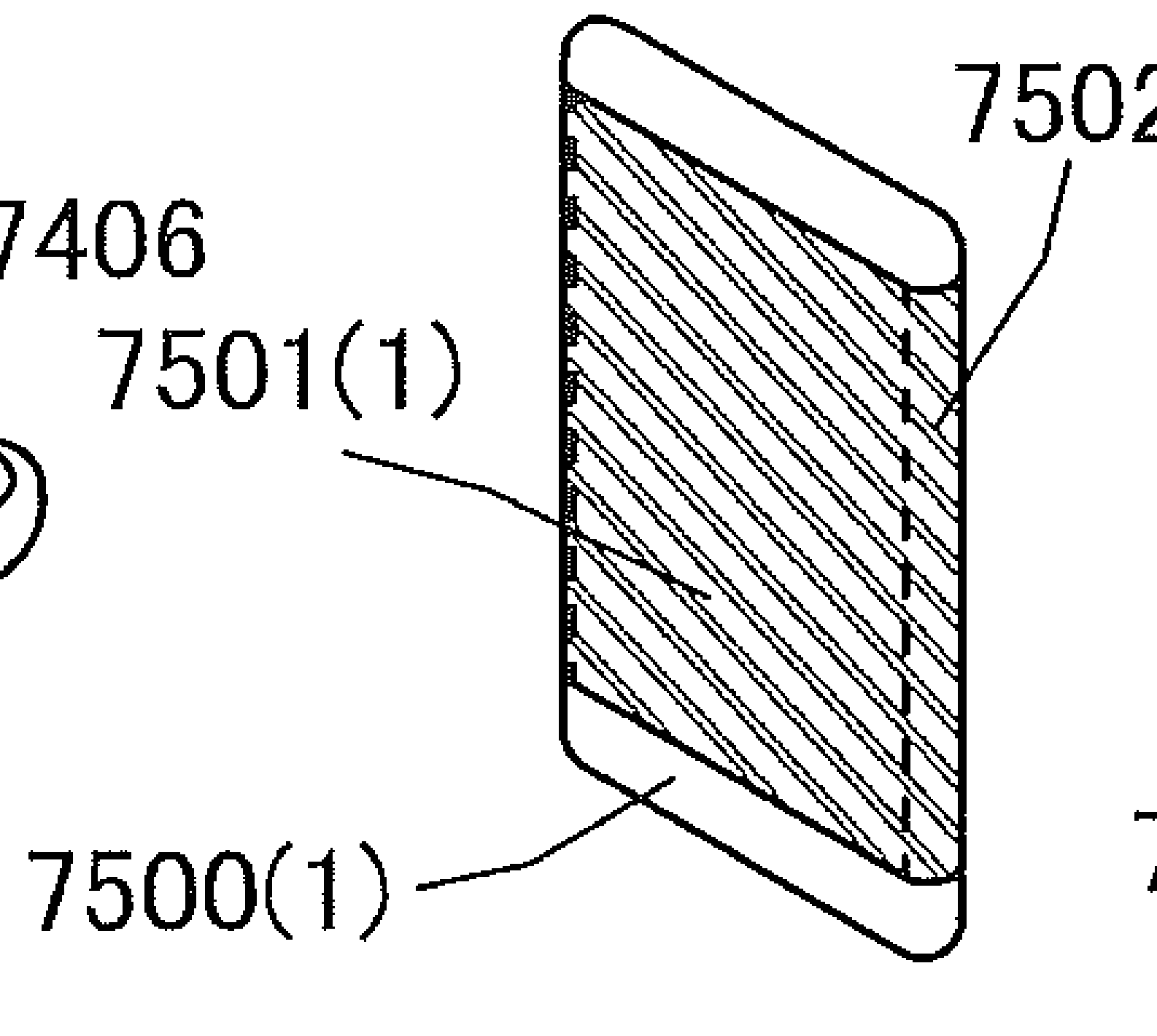


FIG. 8D'-2

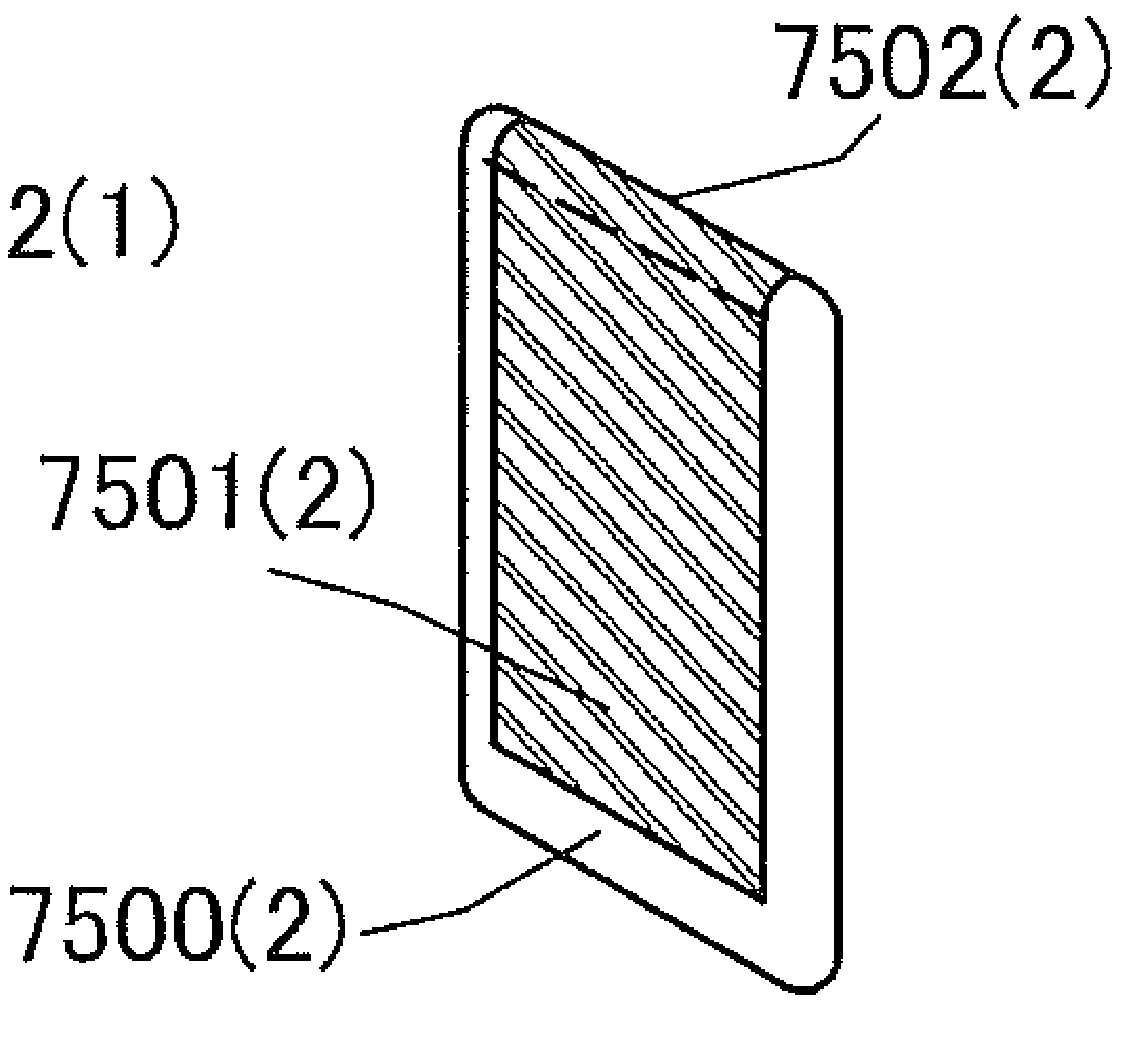


FIG. 9A

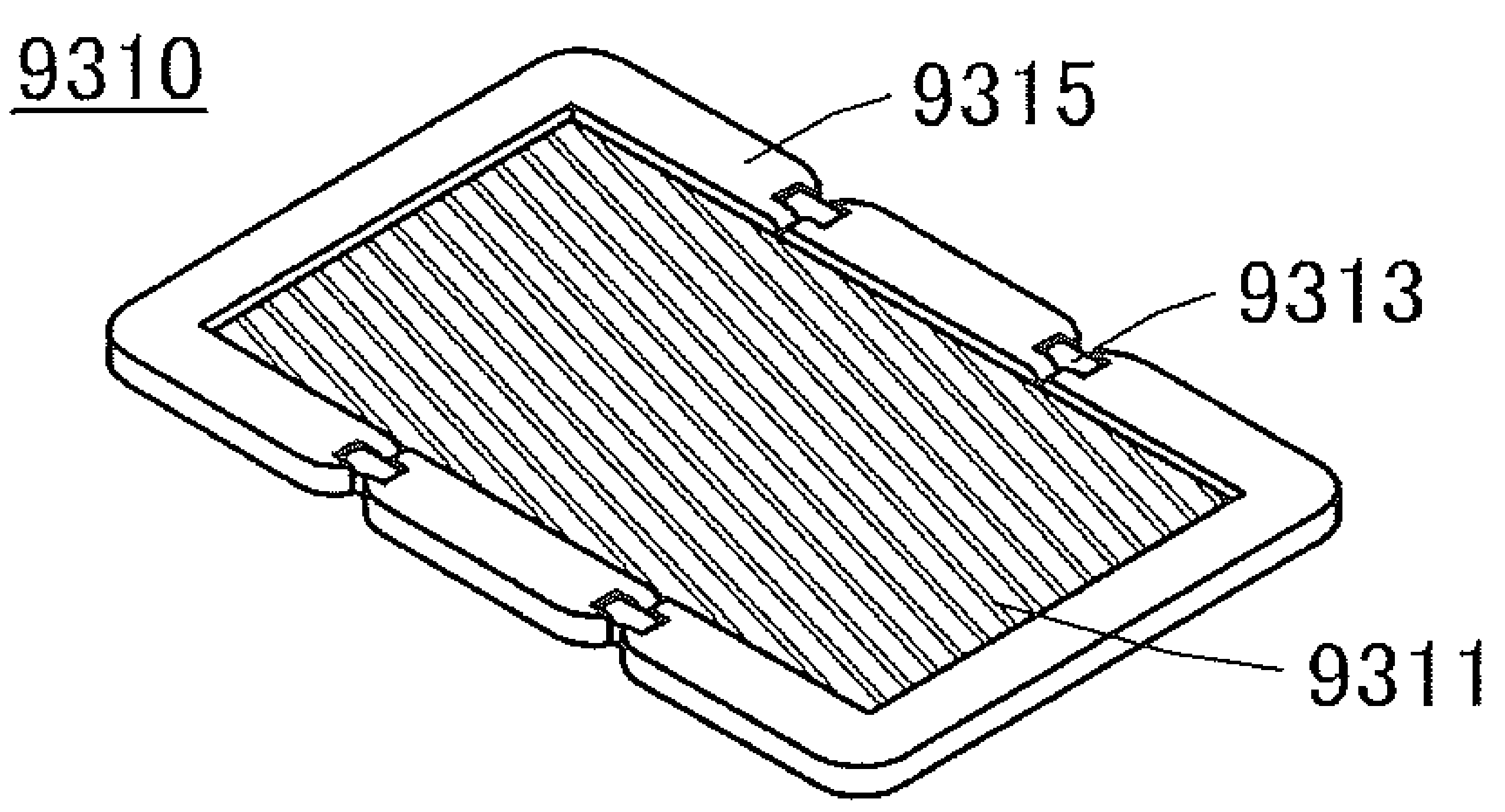


FIG. 9B

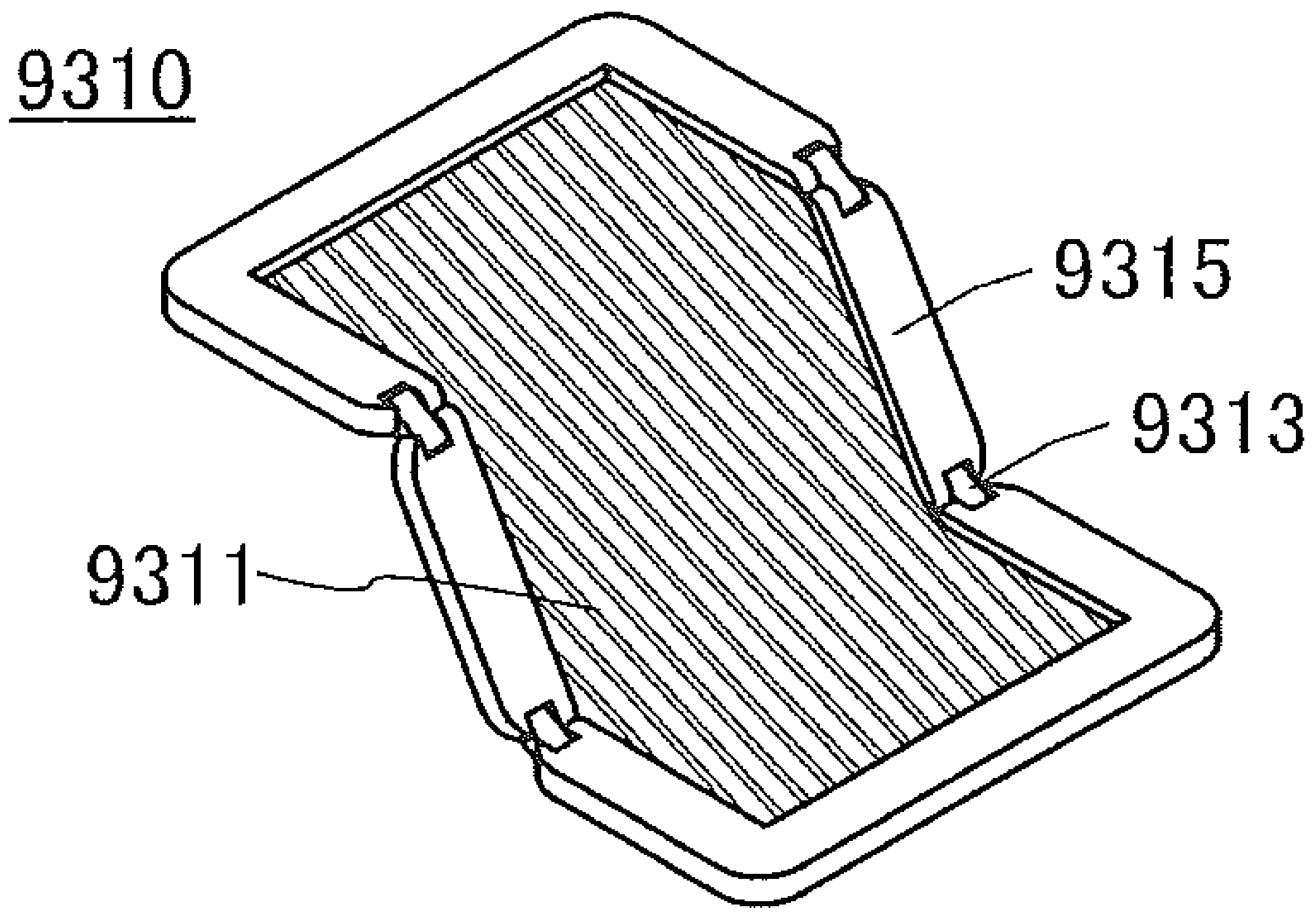
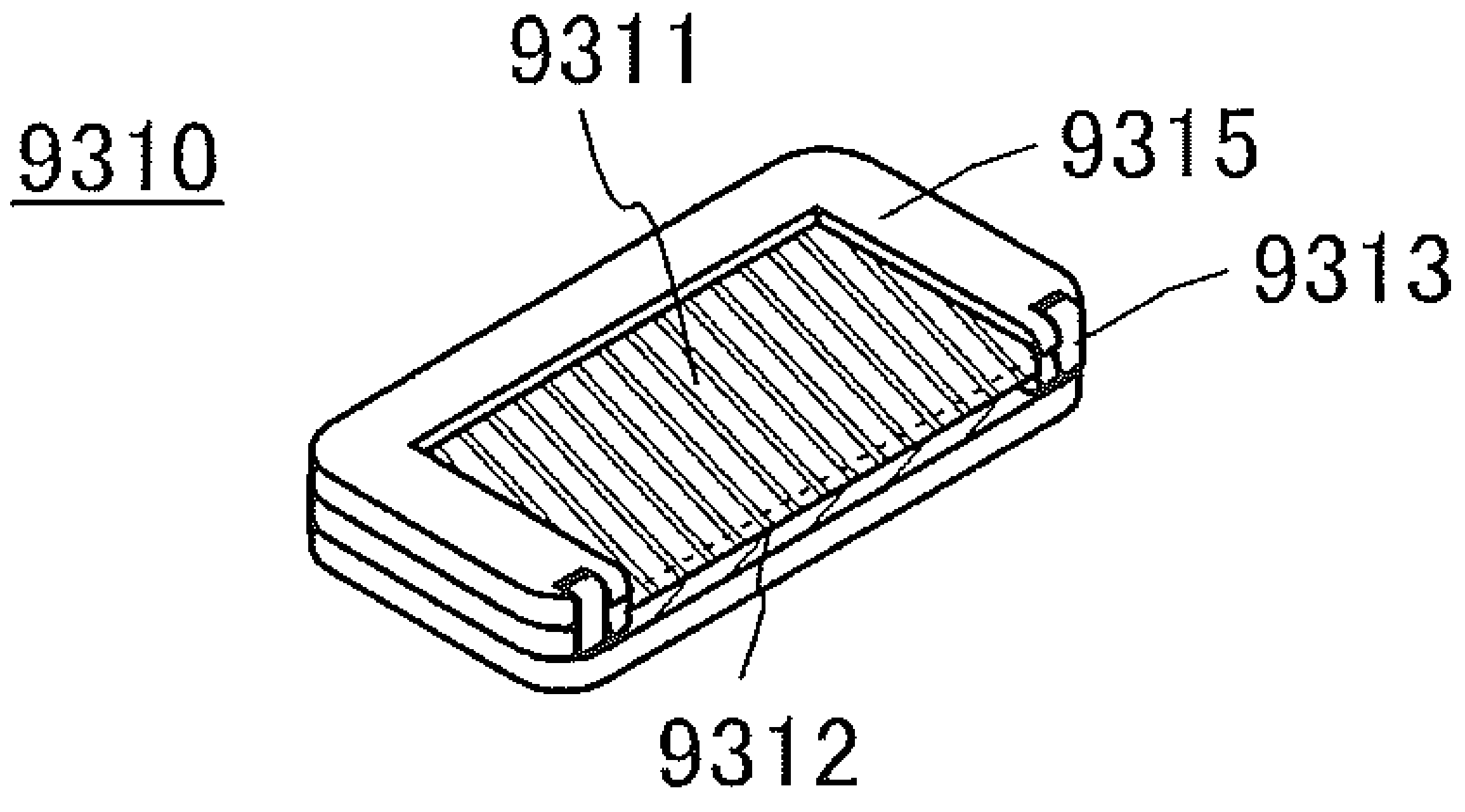


FIG. 9C



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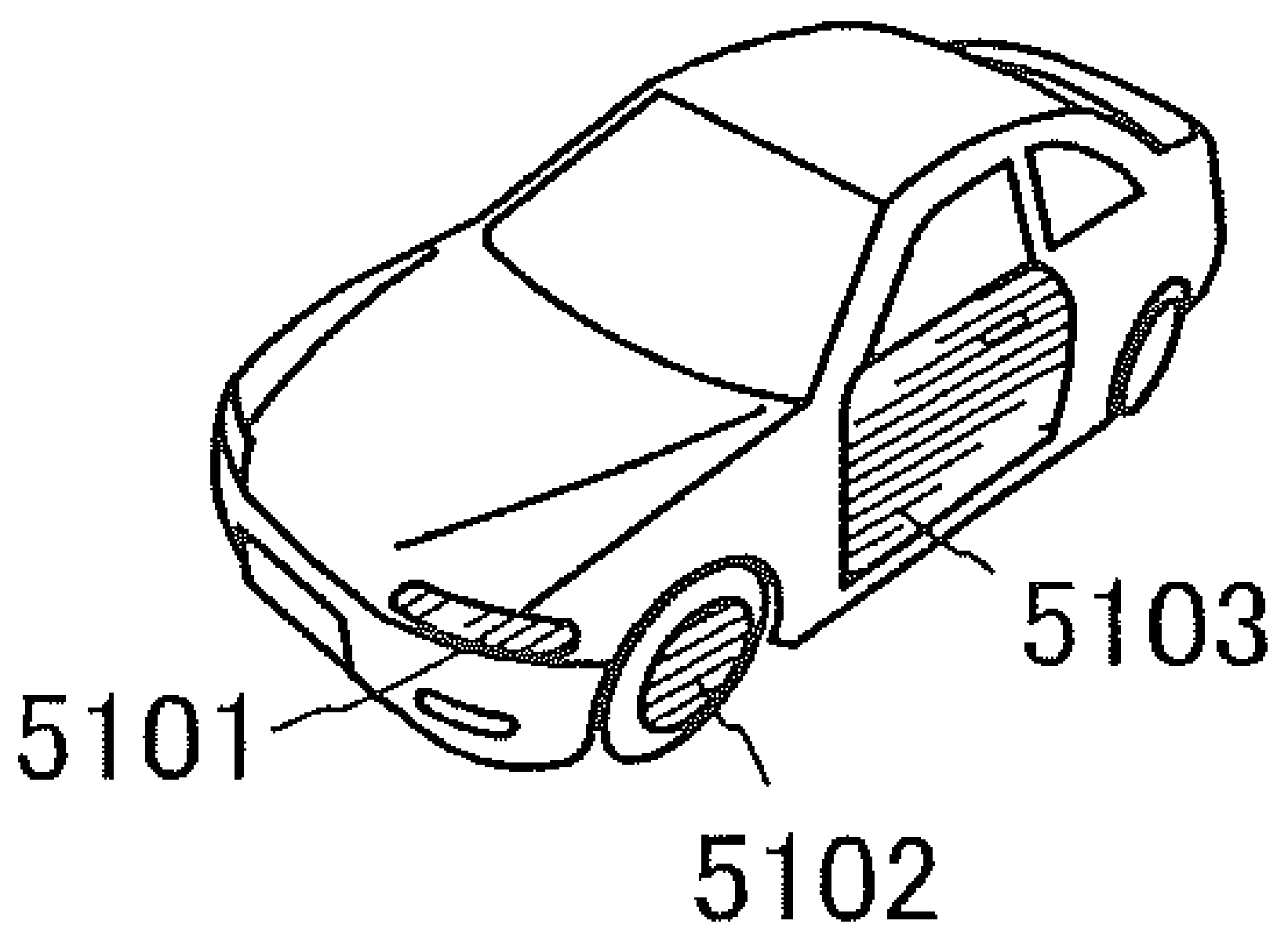

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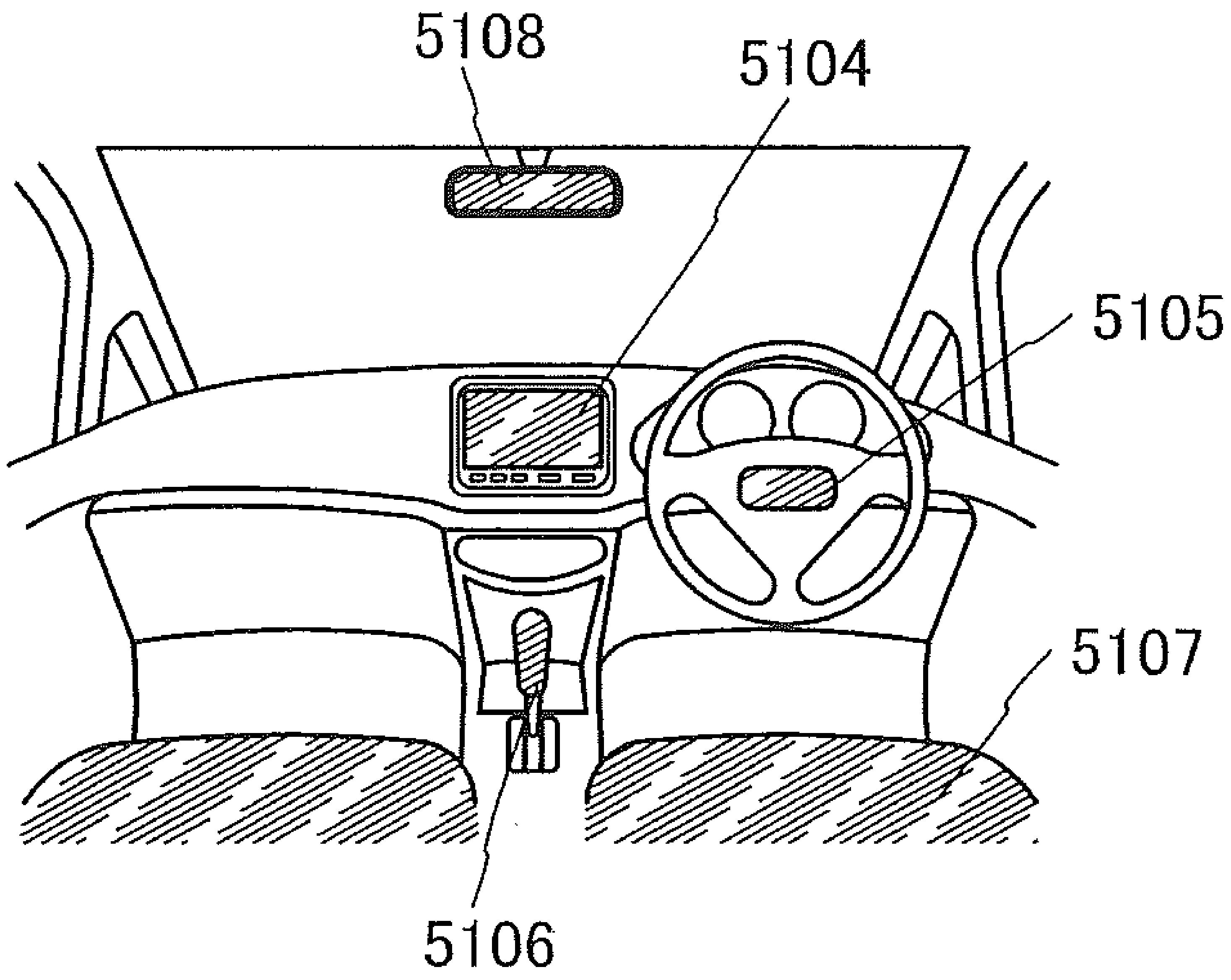

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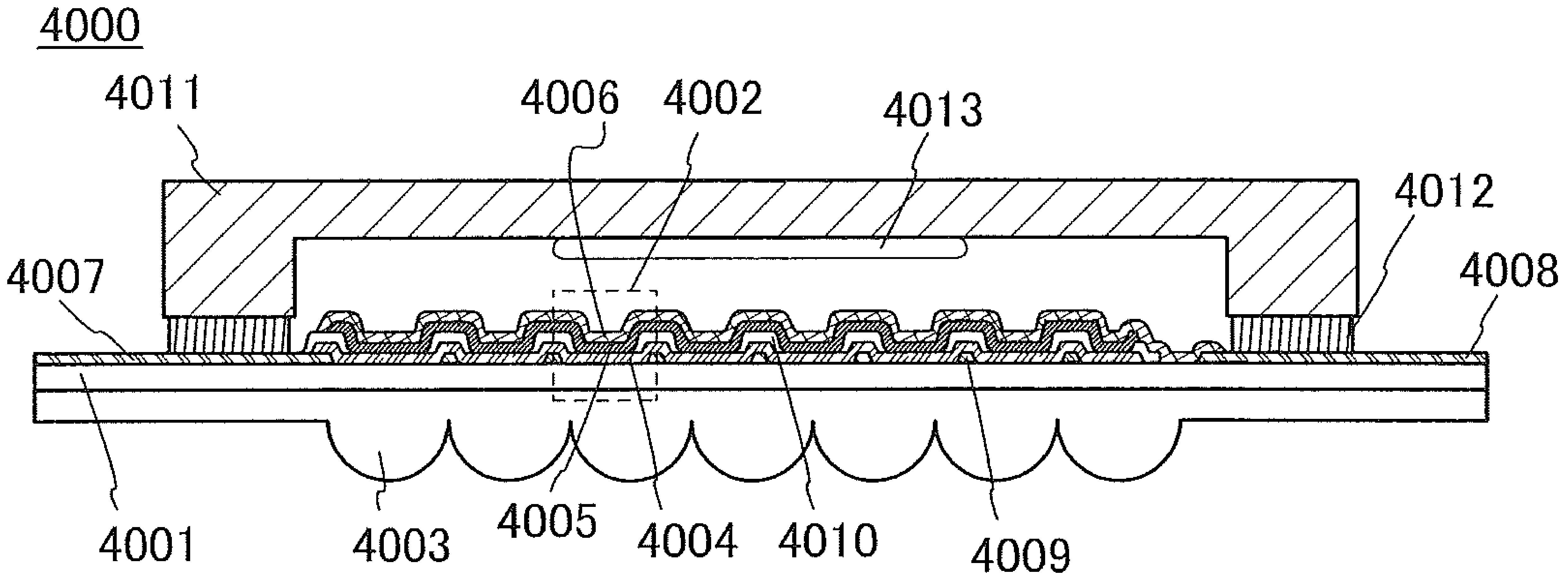

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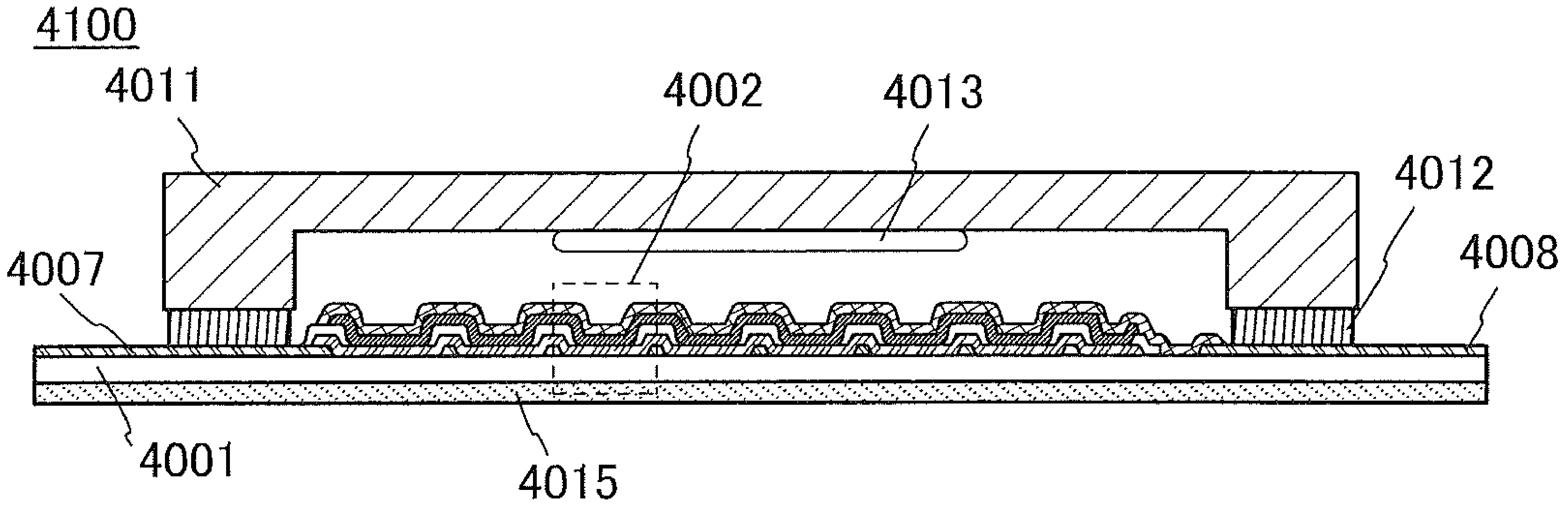

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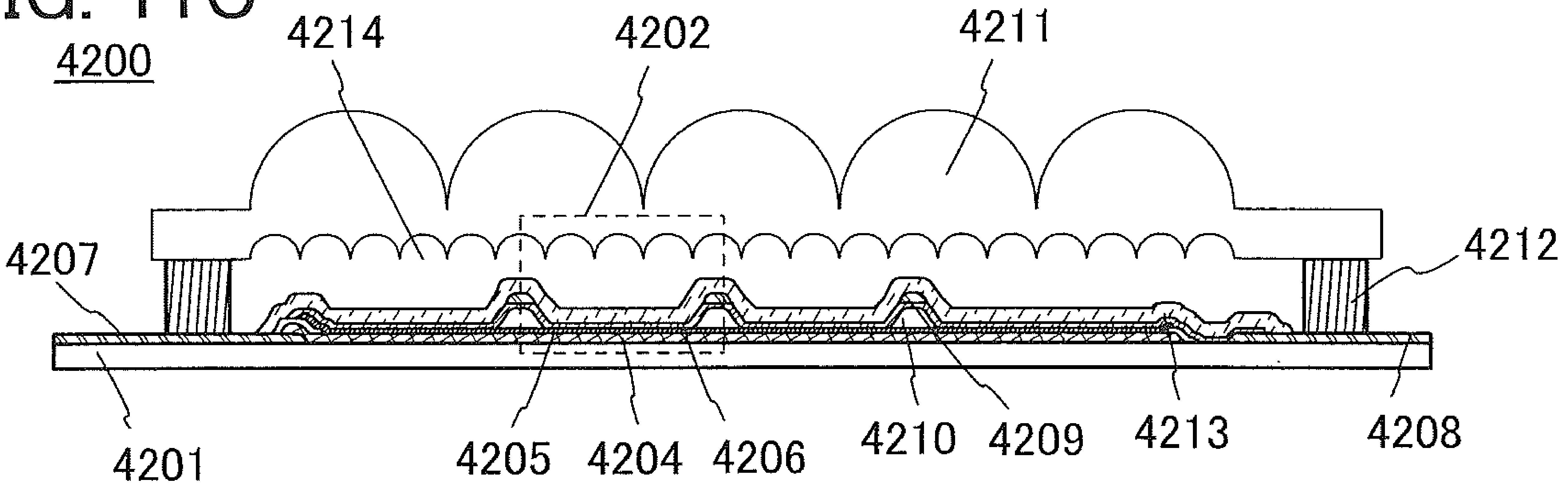

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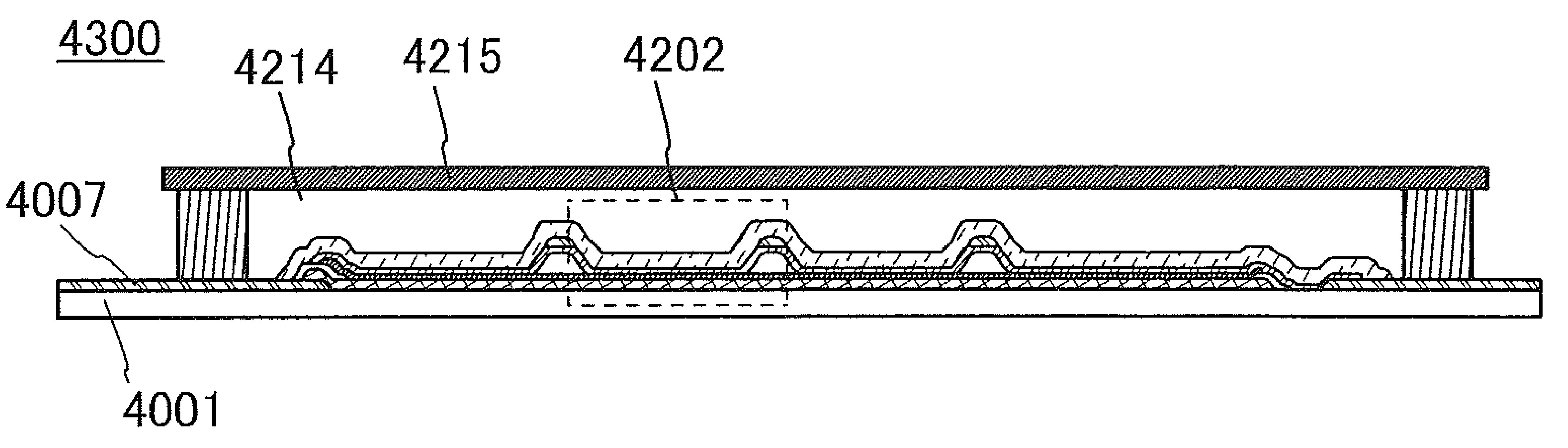


FIG. 12

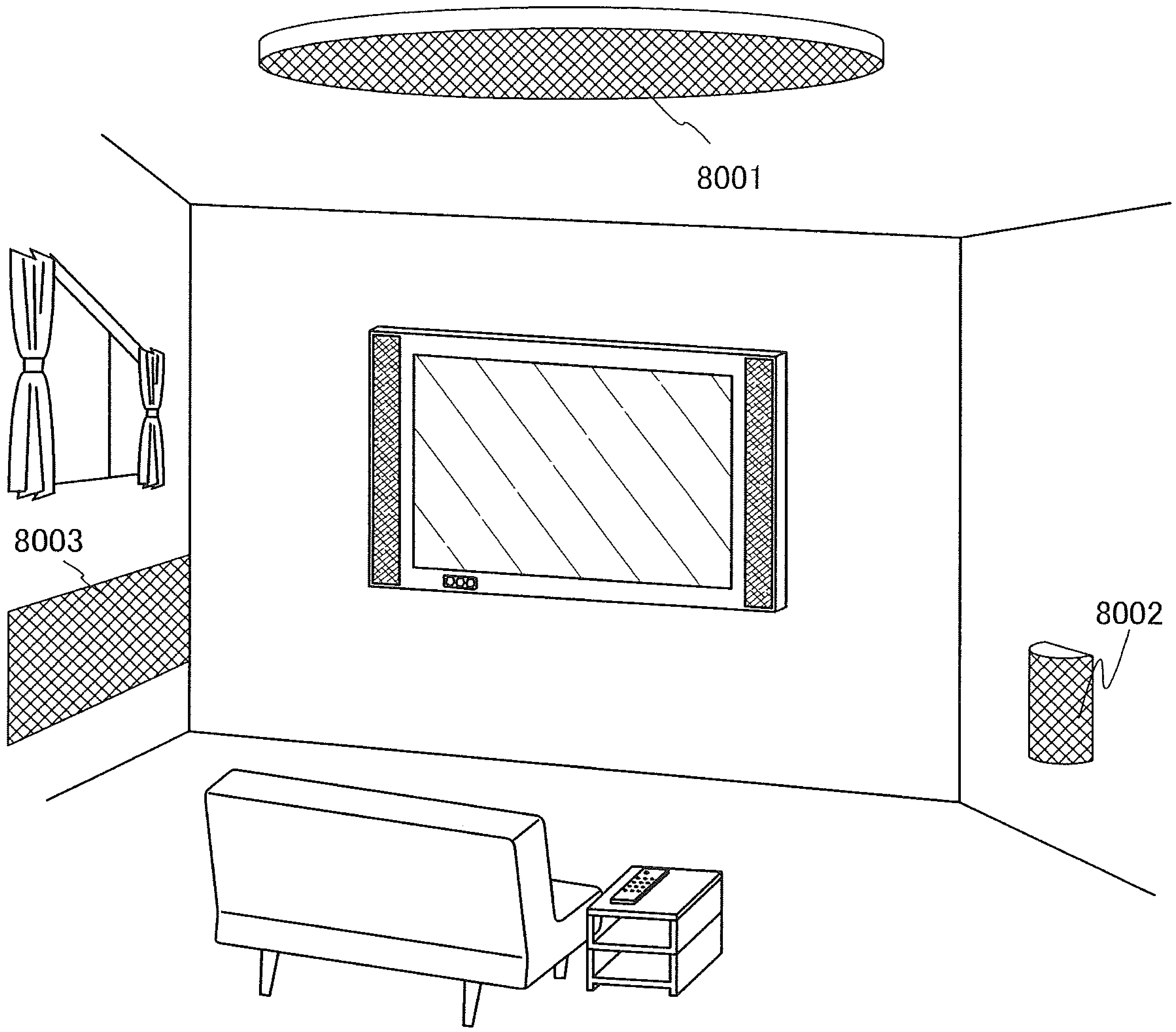


FIG. 13A

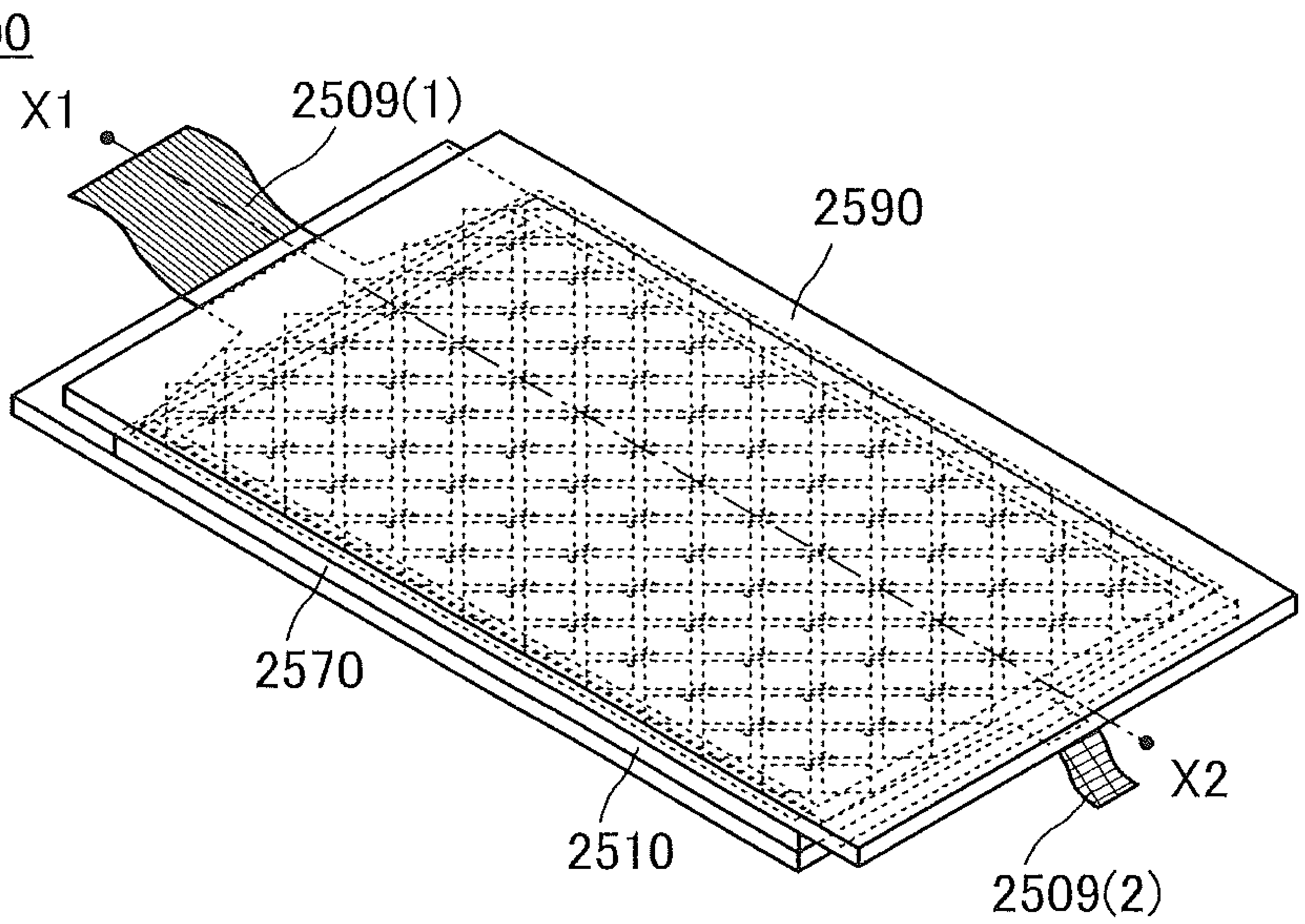


FIG. 13B

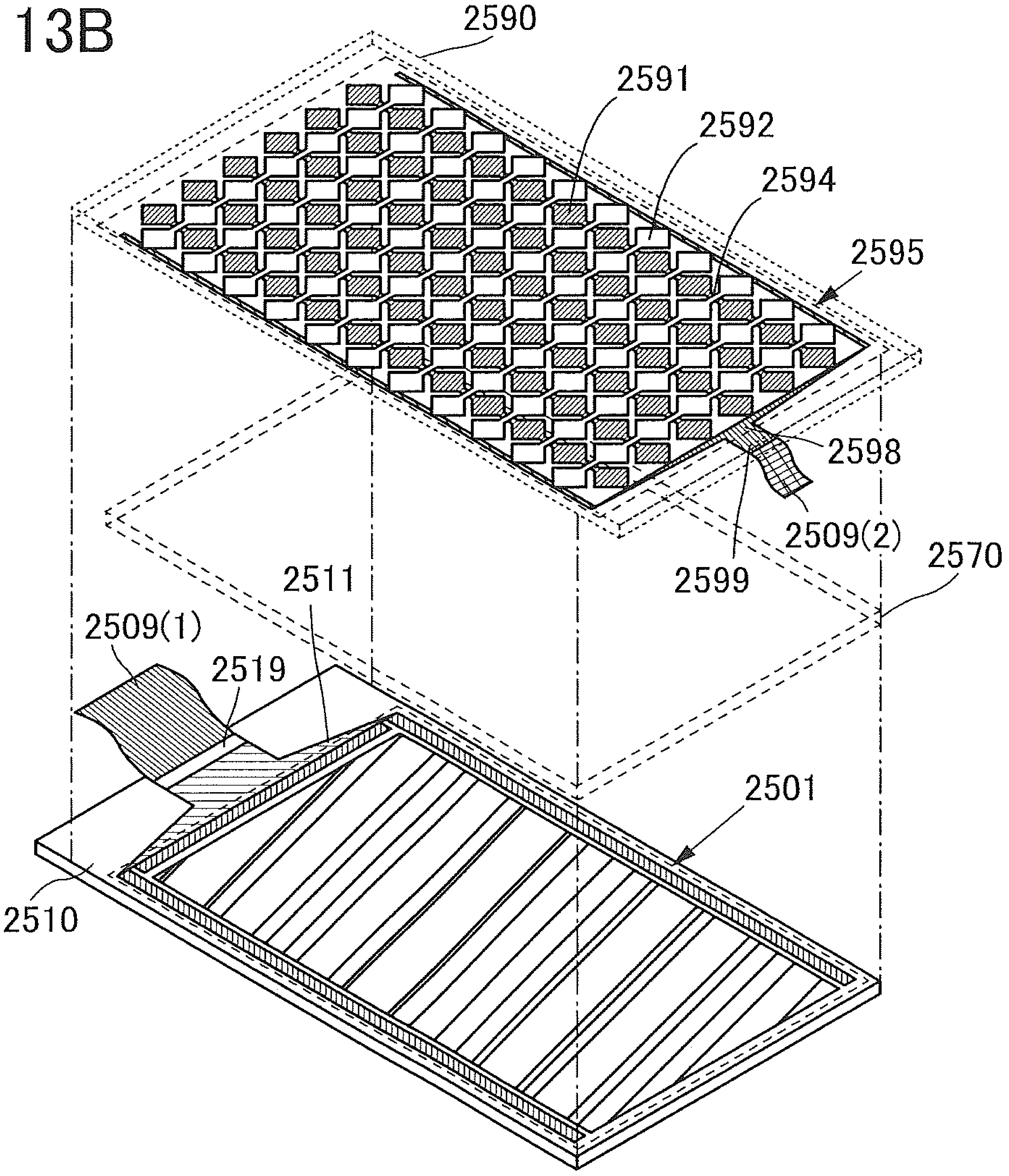


FIG. 14A

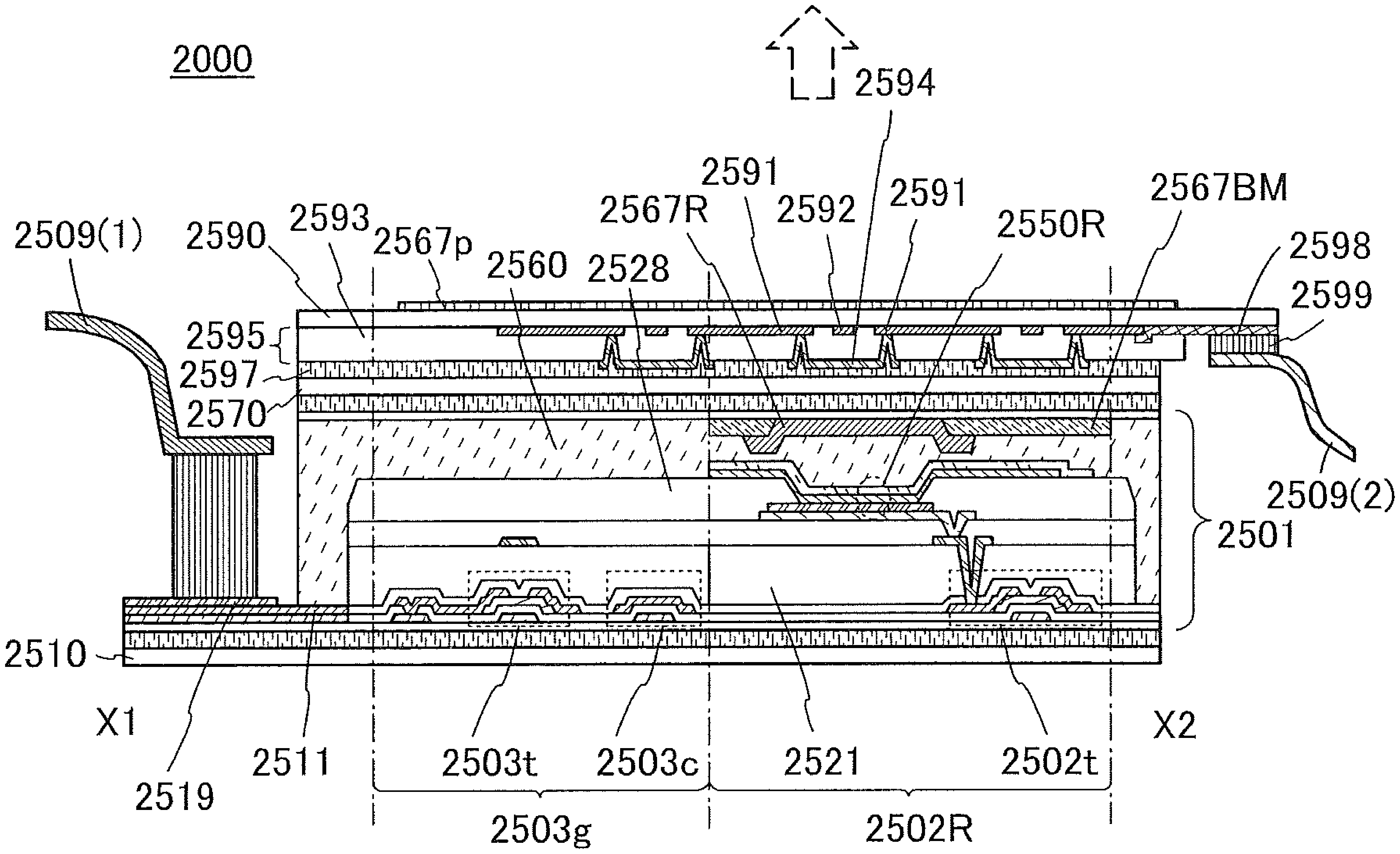


FIG. 14B

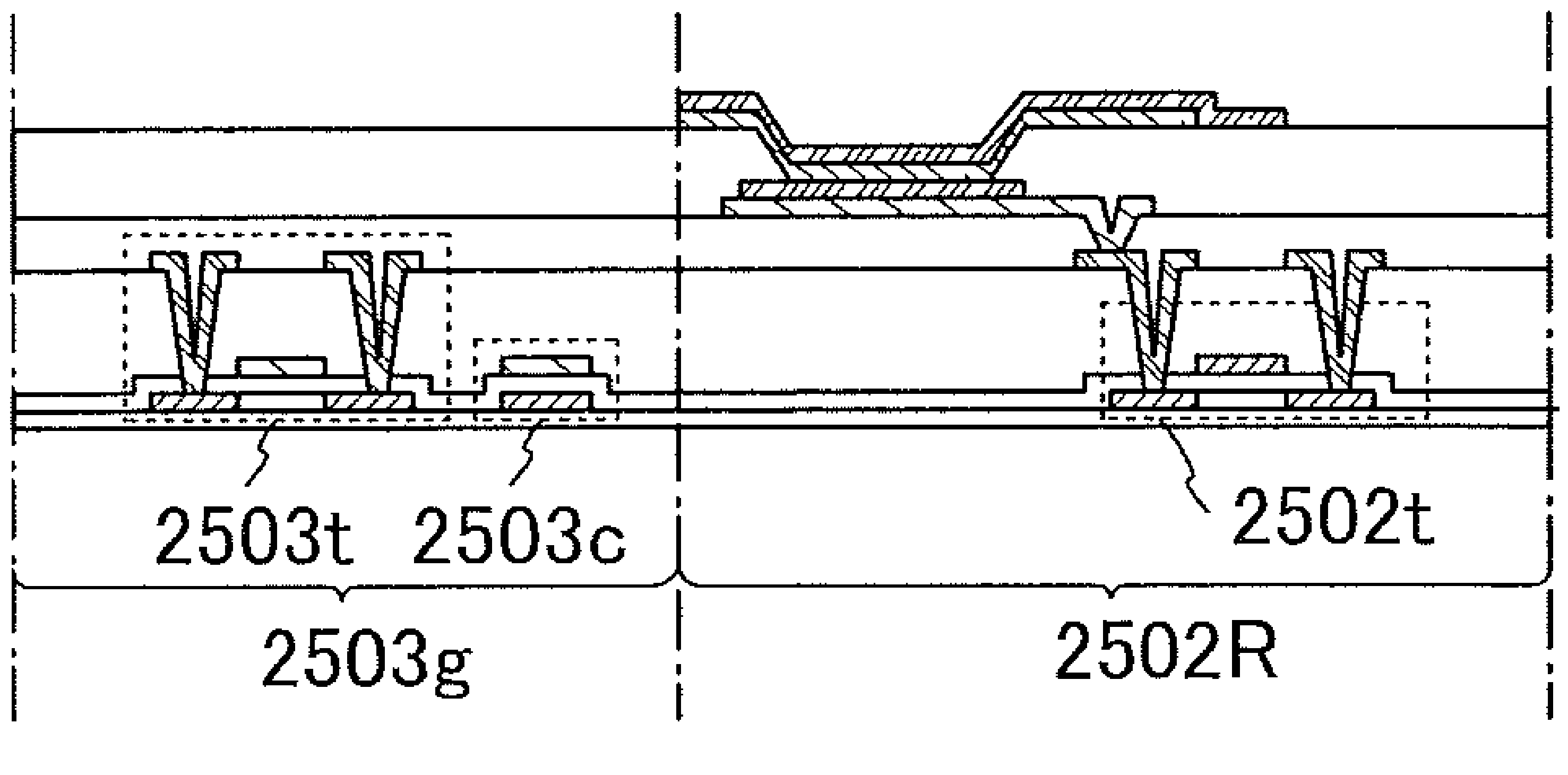
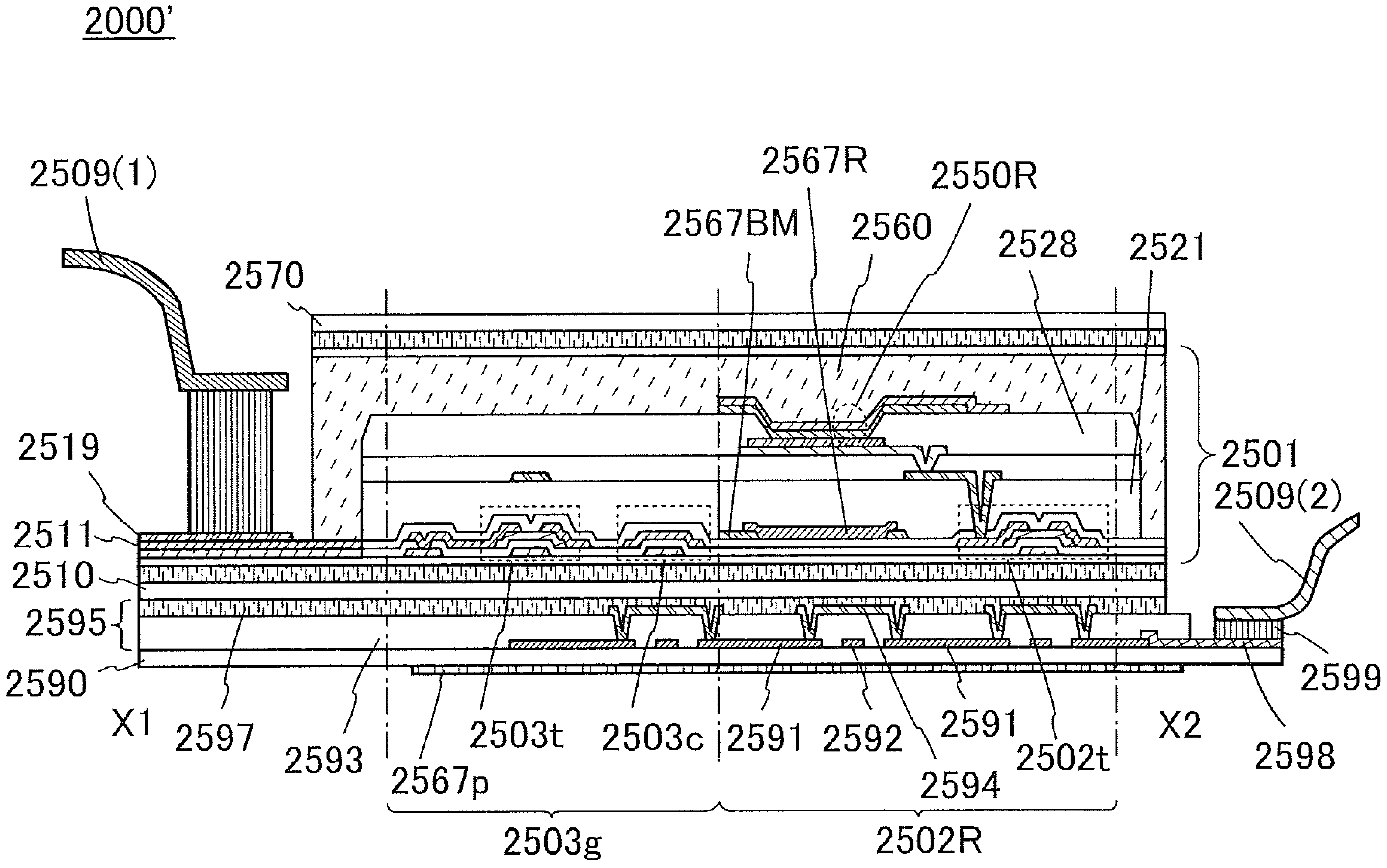
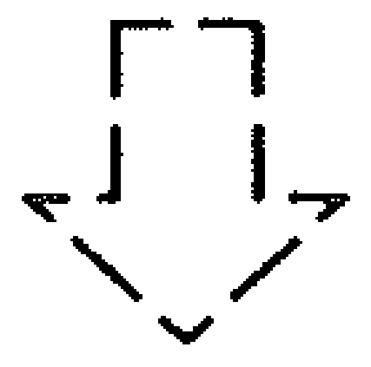


FIG. 15A





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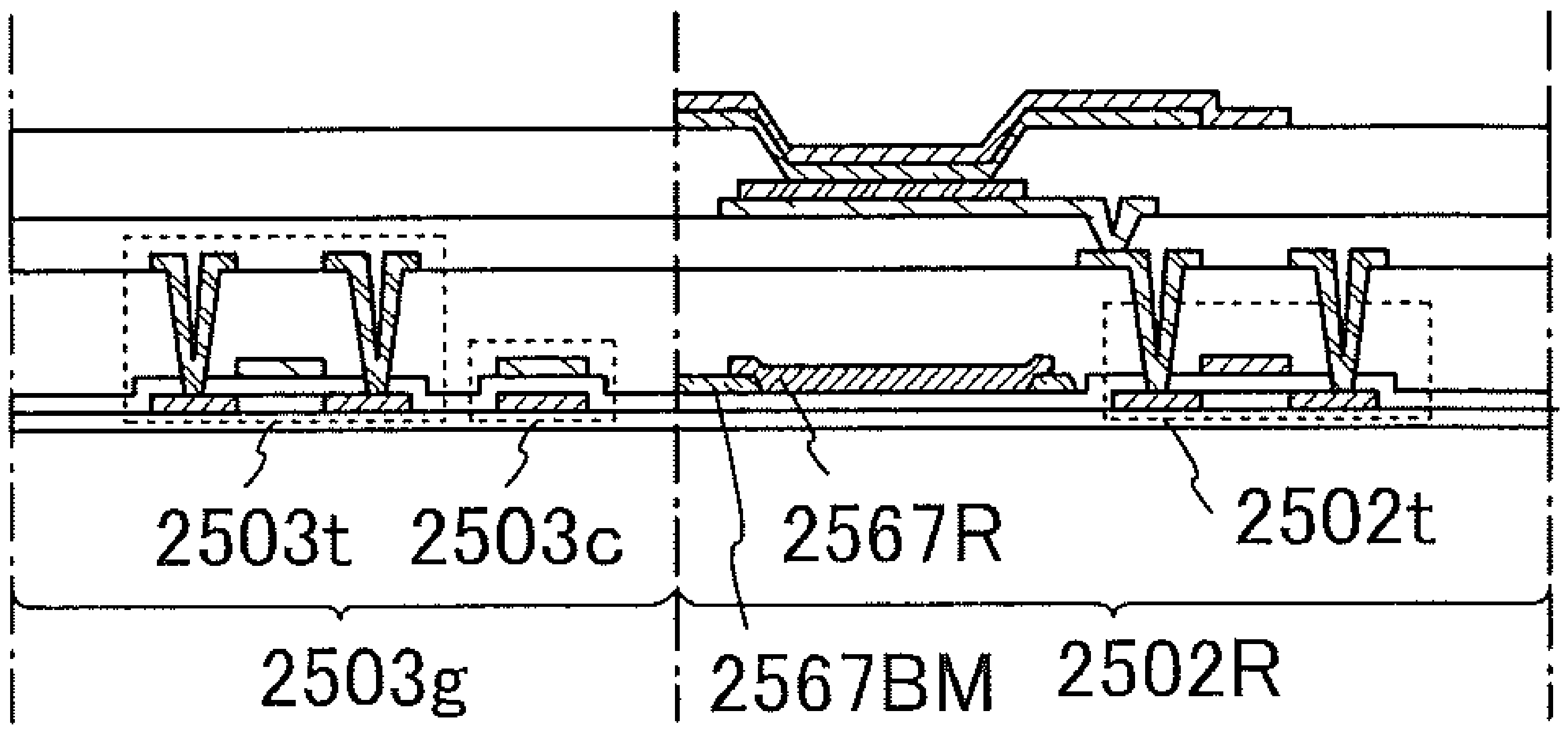


FIG. 16A

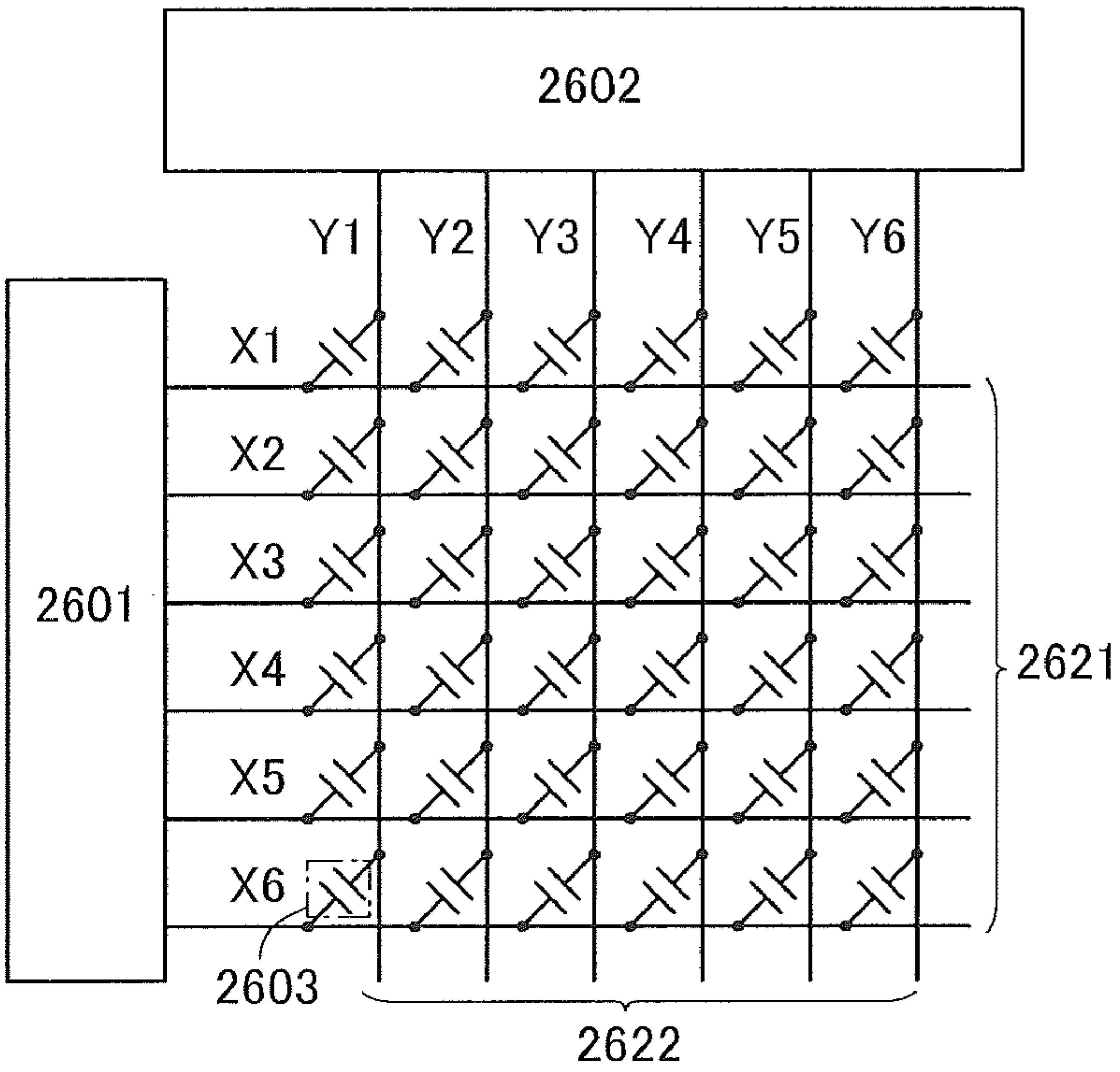


FIG. 16B

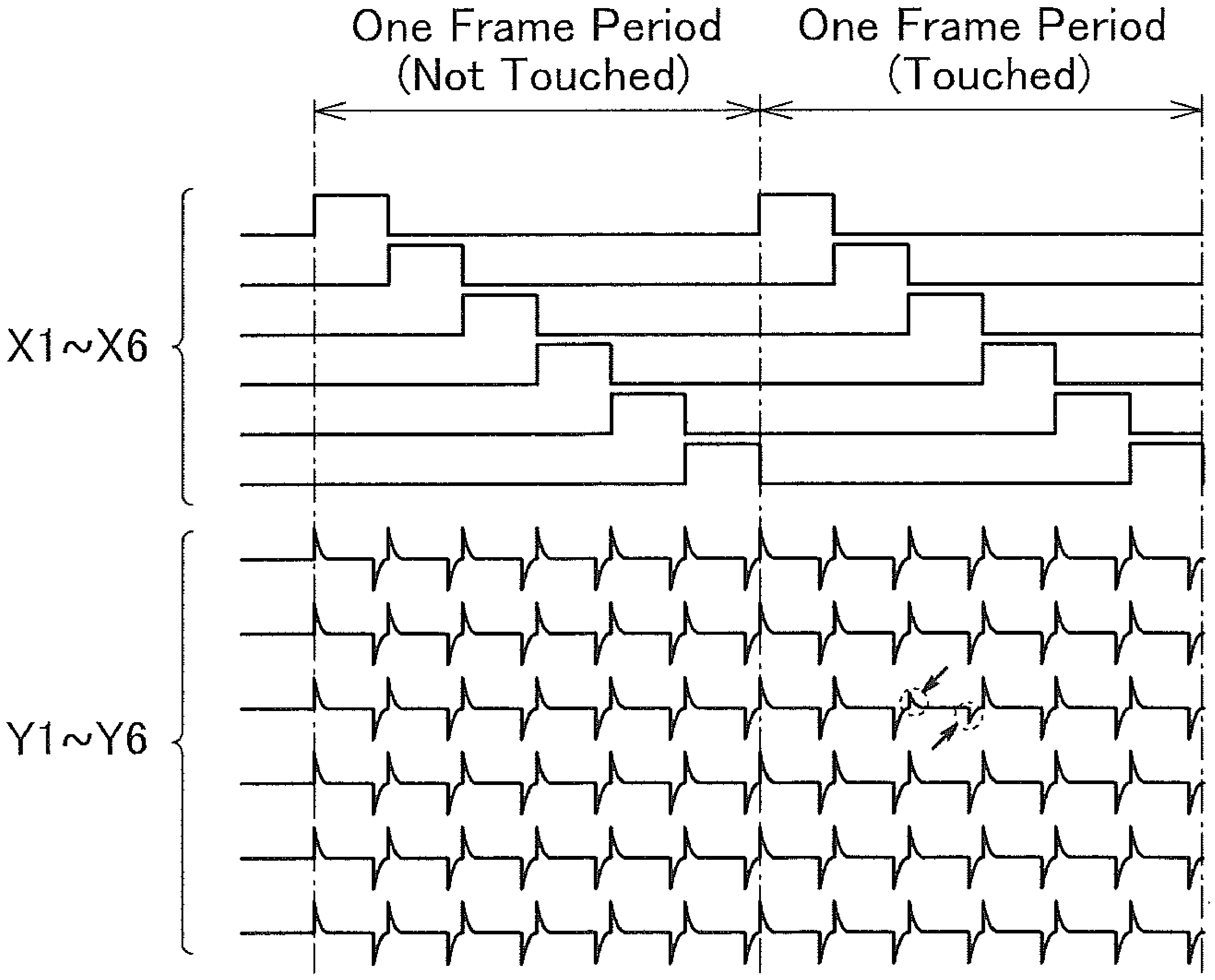


FIG. 17

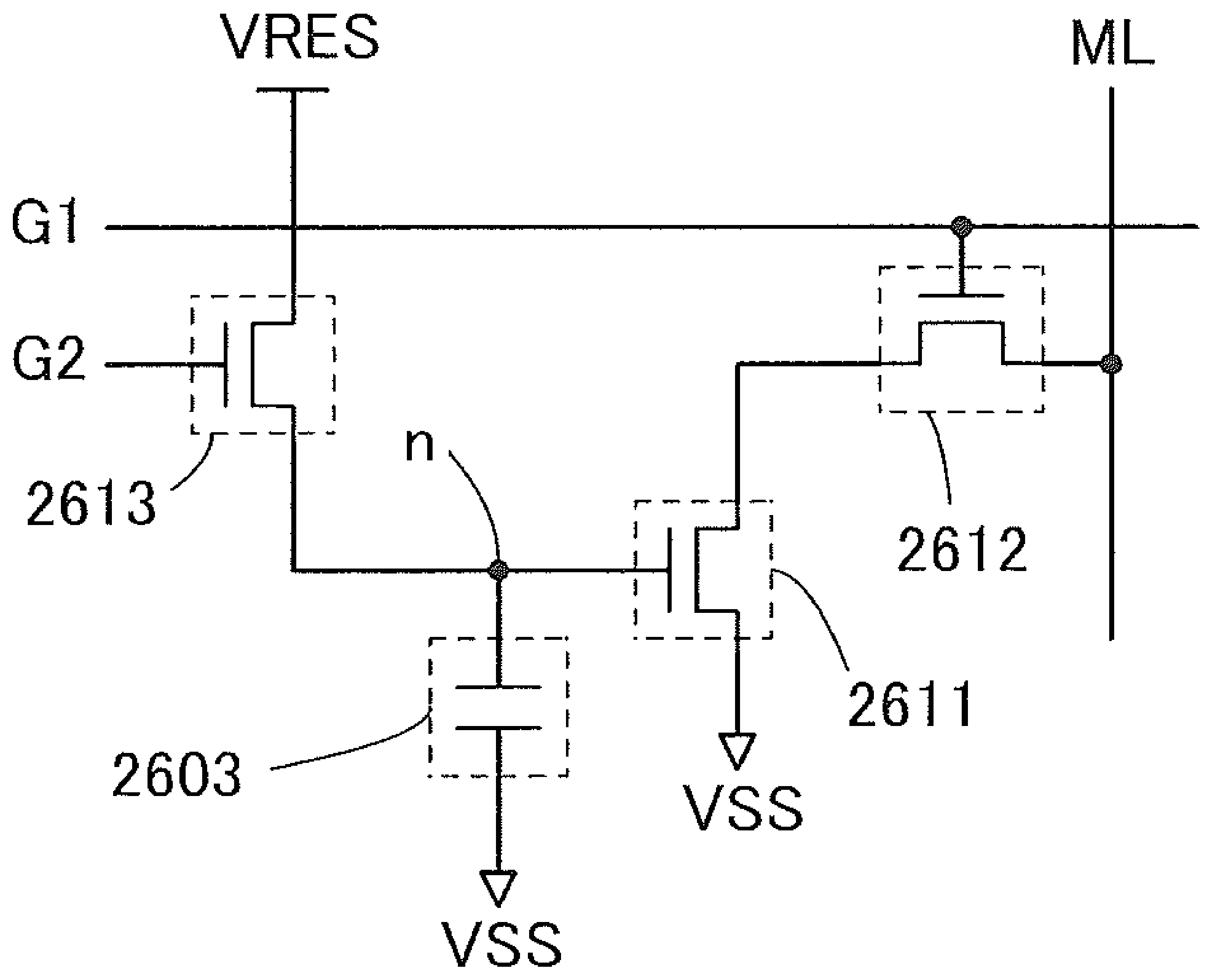


FIG. 18

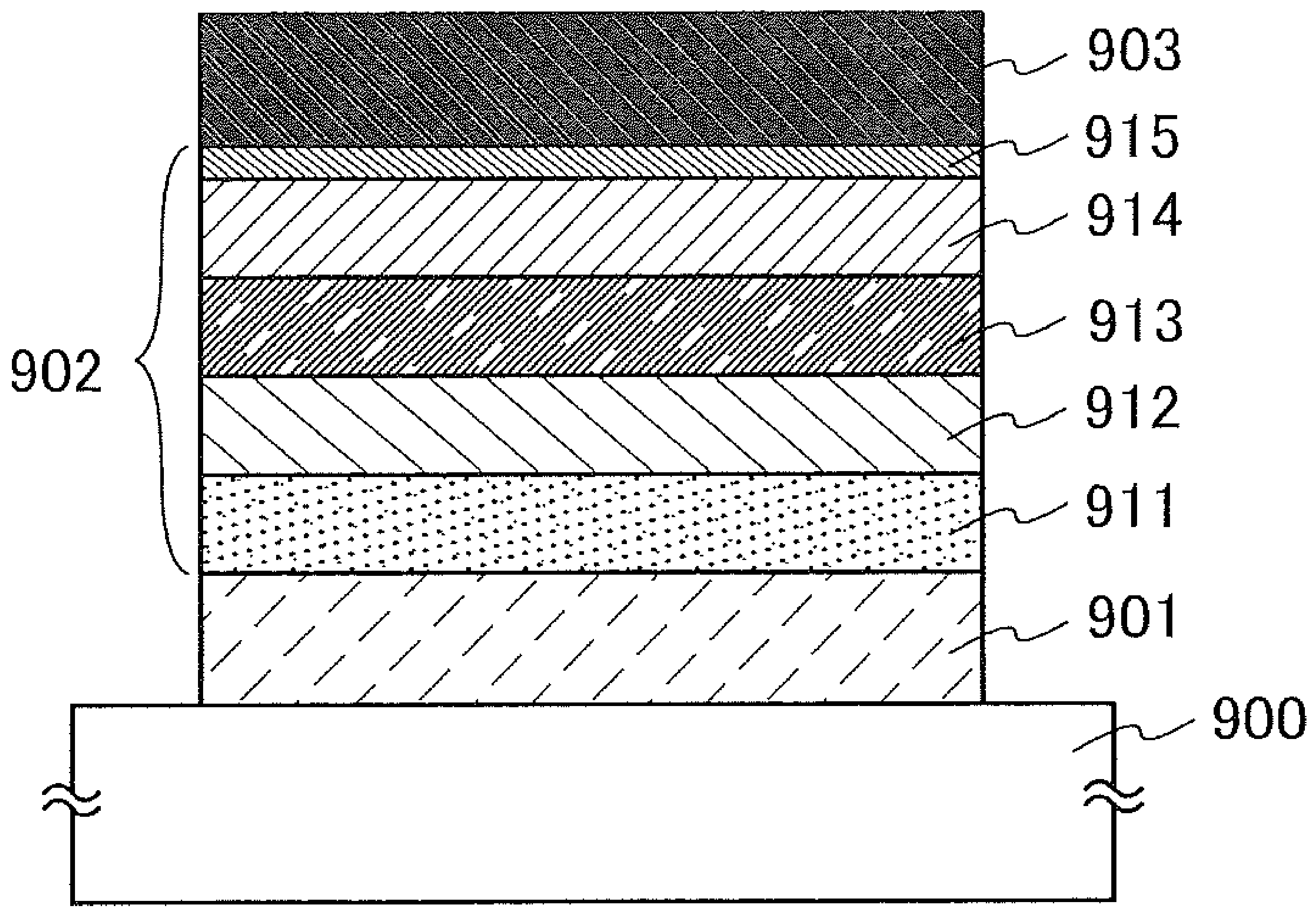


FIG. 19

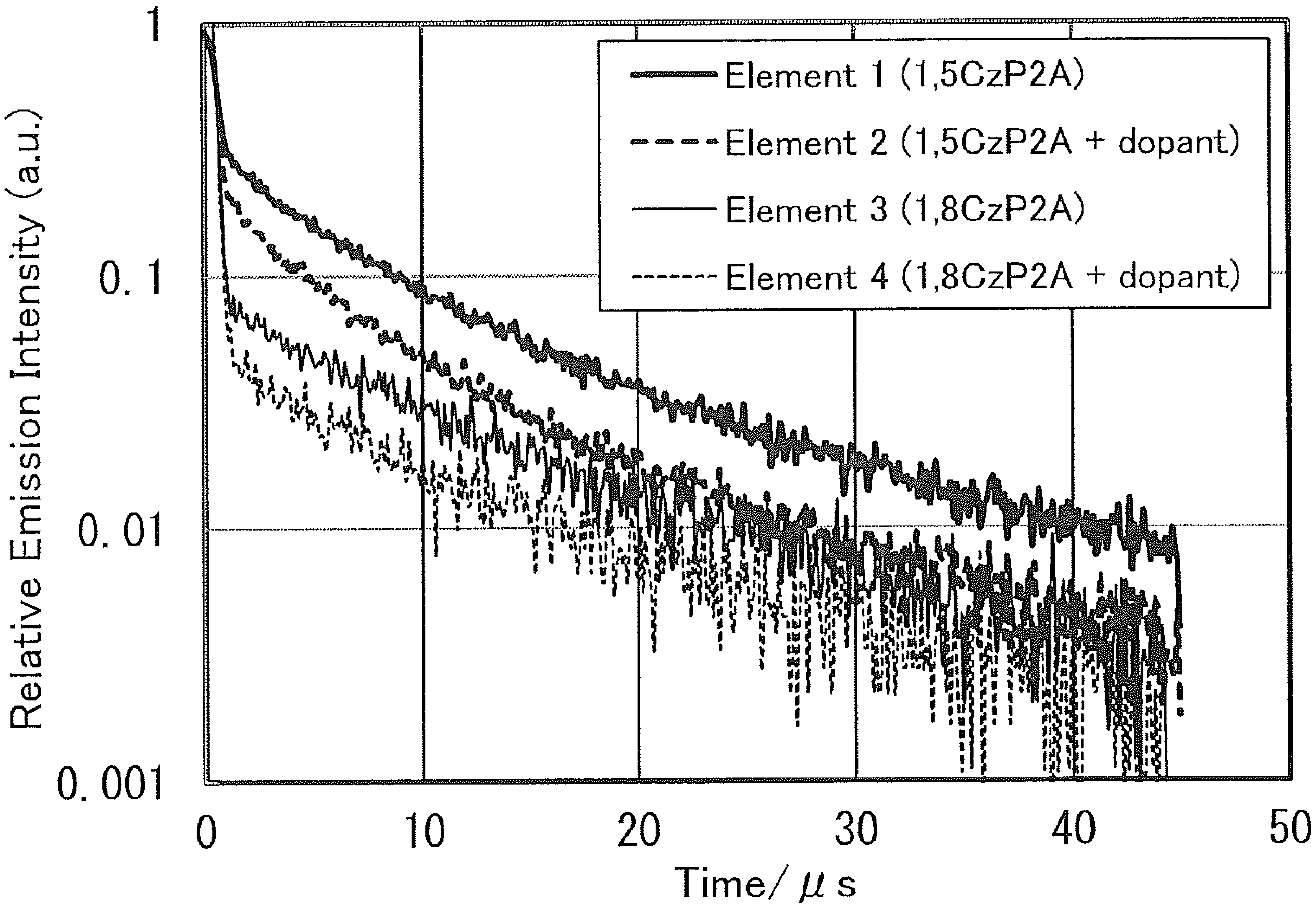

1
0. 1
0. 01
0. 001
Relative Emission Intensity (a.u.)
0
10
20
30
40
50
Time/ μ s
Element 1 (1,5CzP2A)
Element 2 (1,5CzP2A + dopant)
Element 3 (1,8CzP2A)
Element 4 (1,8CzP2A + dopant)

FIG. 20

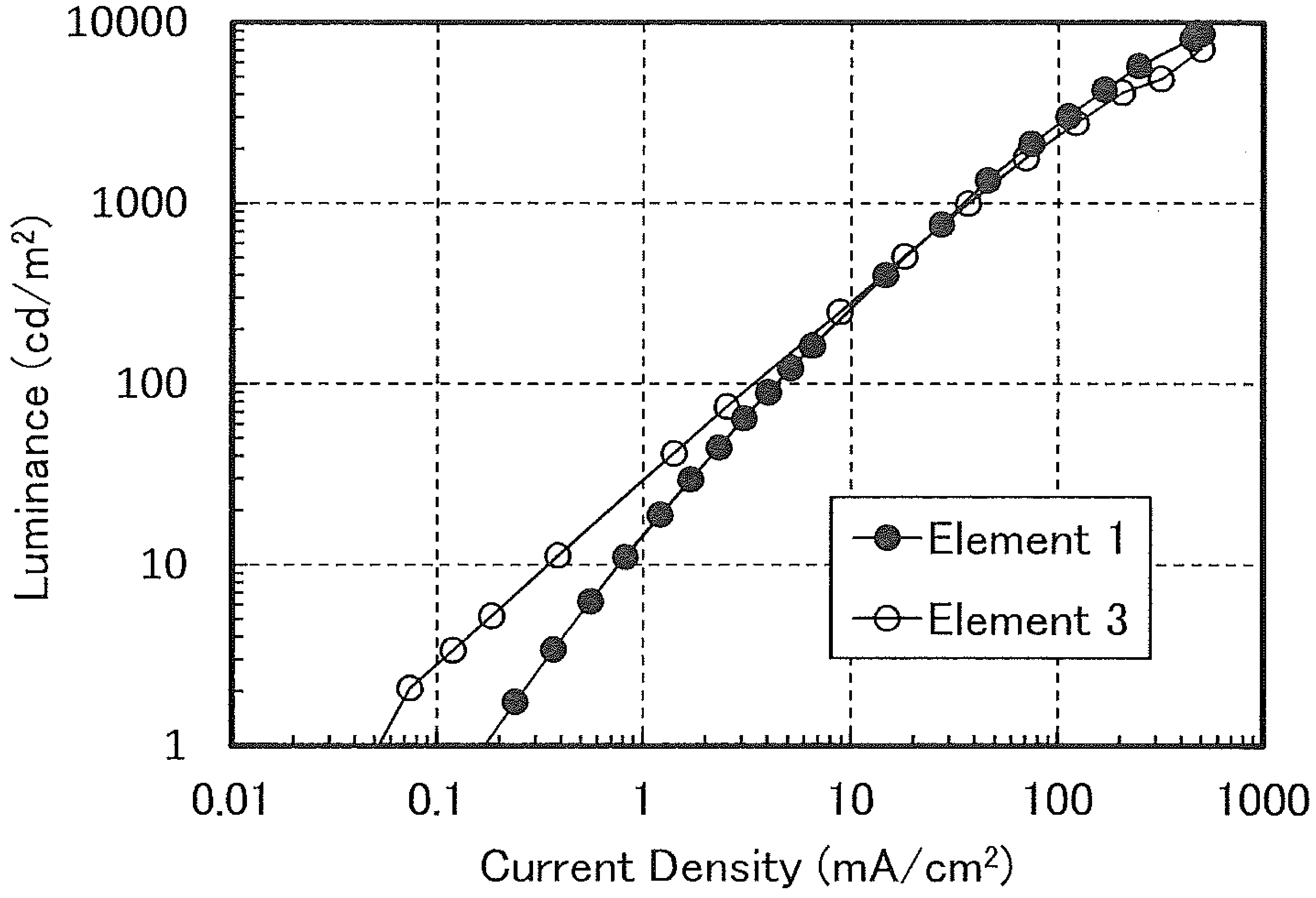

10000
1000
100
10
1
Luminance (cd/m2)
0.01
0.1
1
10
100
1000
Current Density (mA/cm2)
●Element 1
○Element 3

FIG. 21

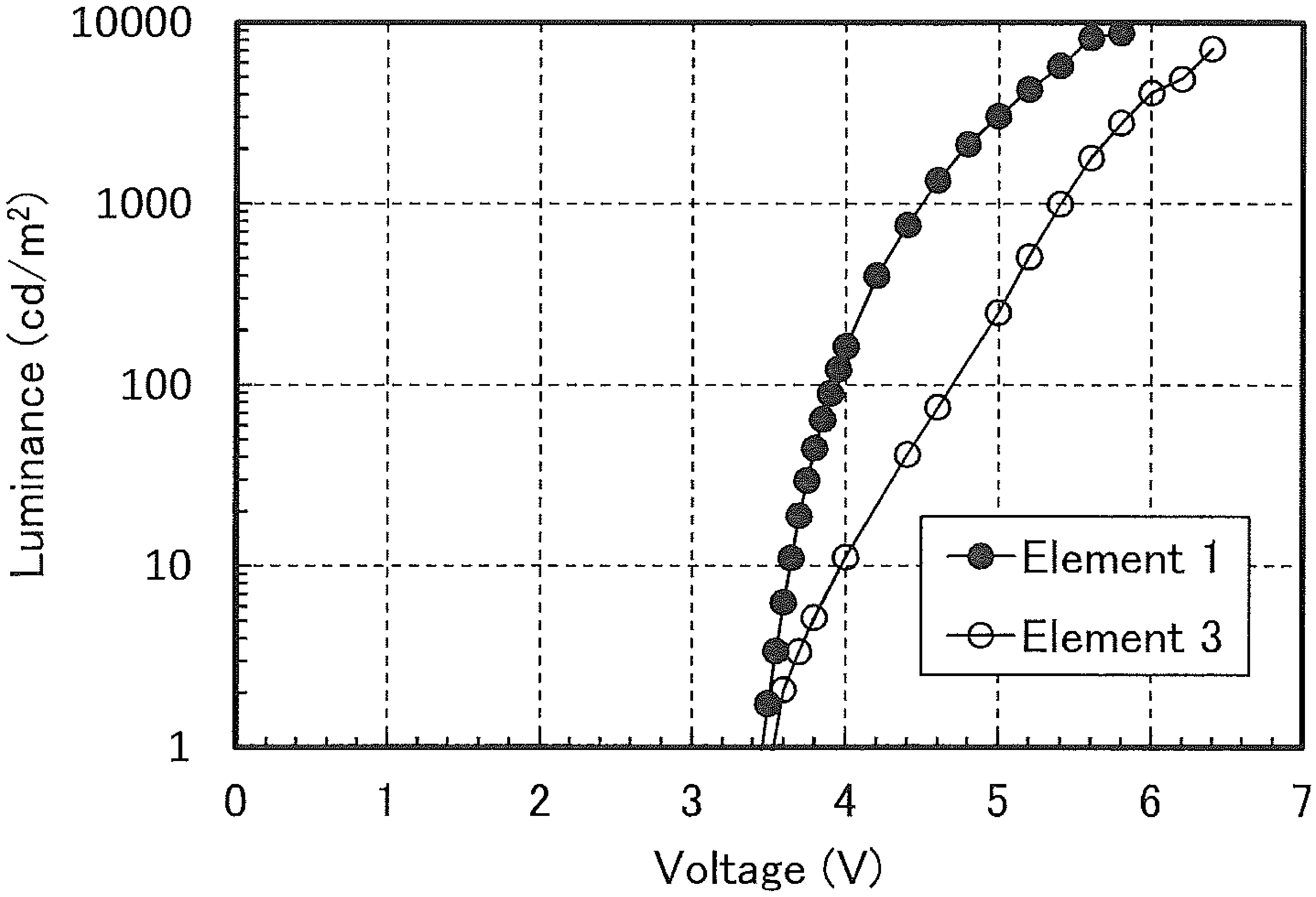

10000
1000
100
10
1
Luminance (cd/m2)
0
1
2
3
4
5
6
7
Voltage (V)
●Element 1
○Element 3

FIG. 22

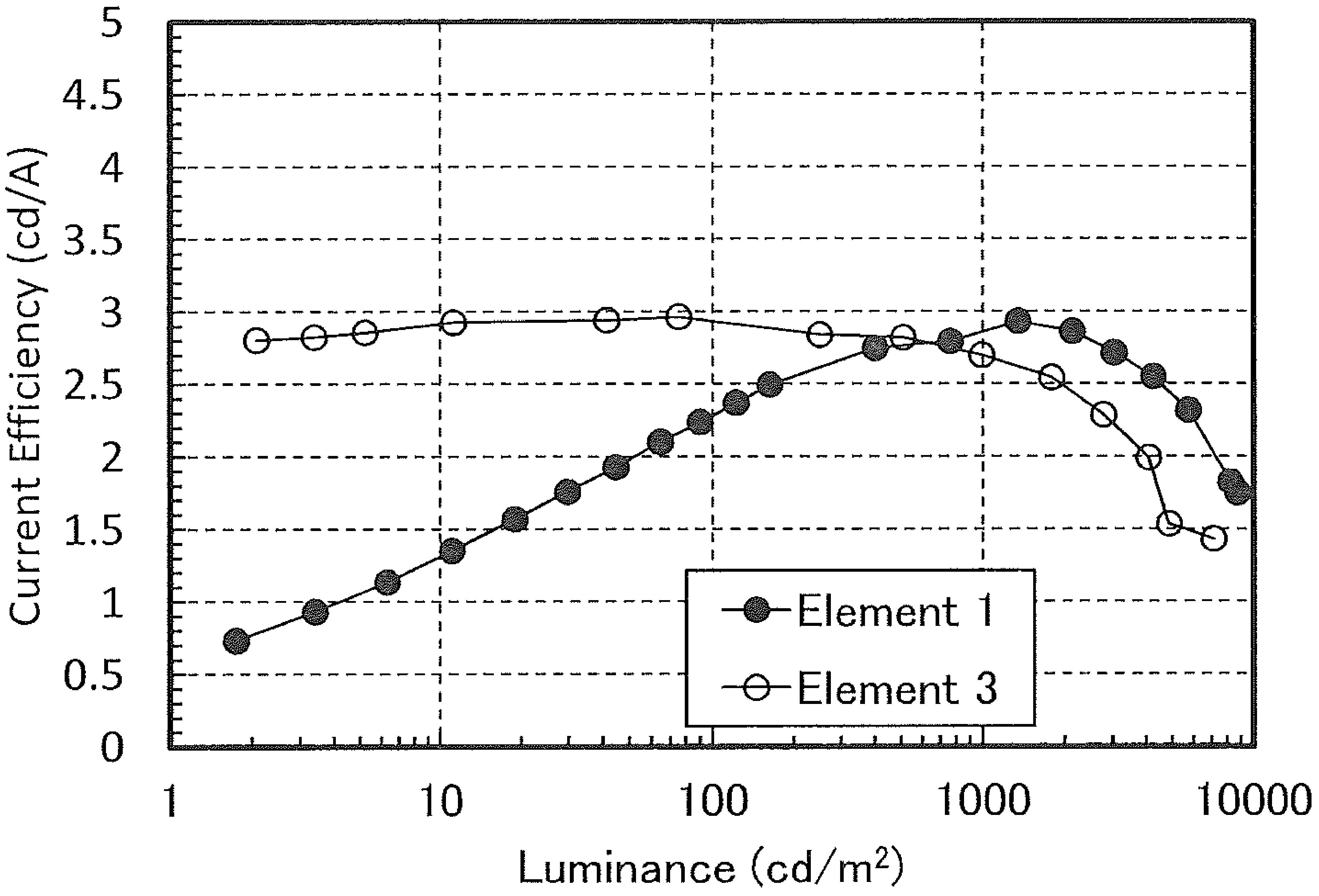

Current Efficiency (cd/A)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Luminance (cd/m²)
1
10
100
1000
10000
Element 1
Element 3

FIG. 23

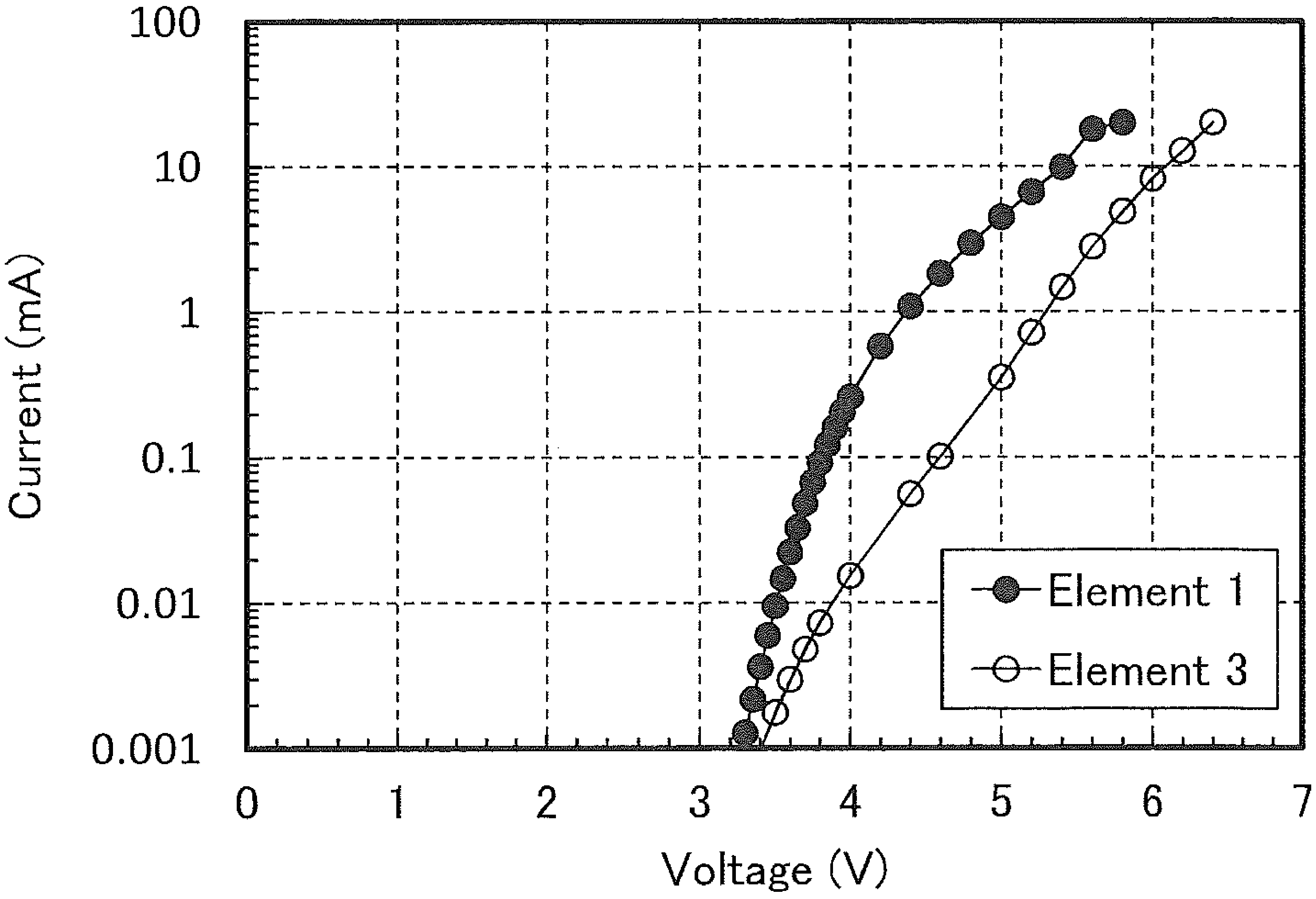

Current (mA)
0.001
0.01
0.1
1
10
100
Voltage (V)
0
1
2
3
4
5
6
7
Element 1
Element 3

FIG. 24

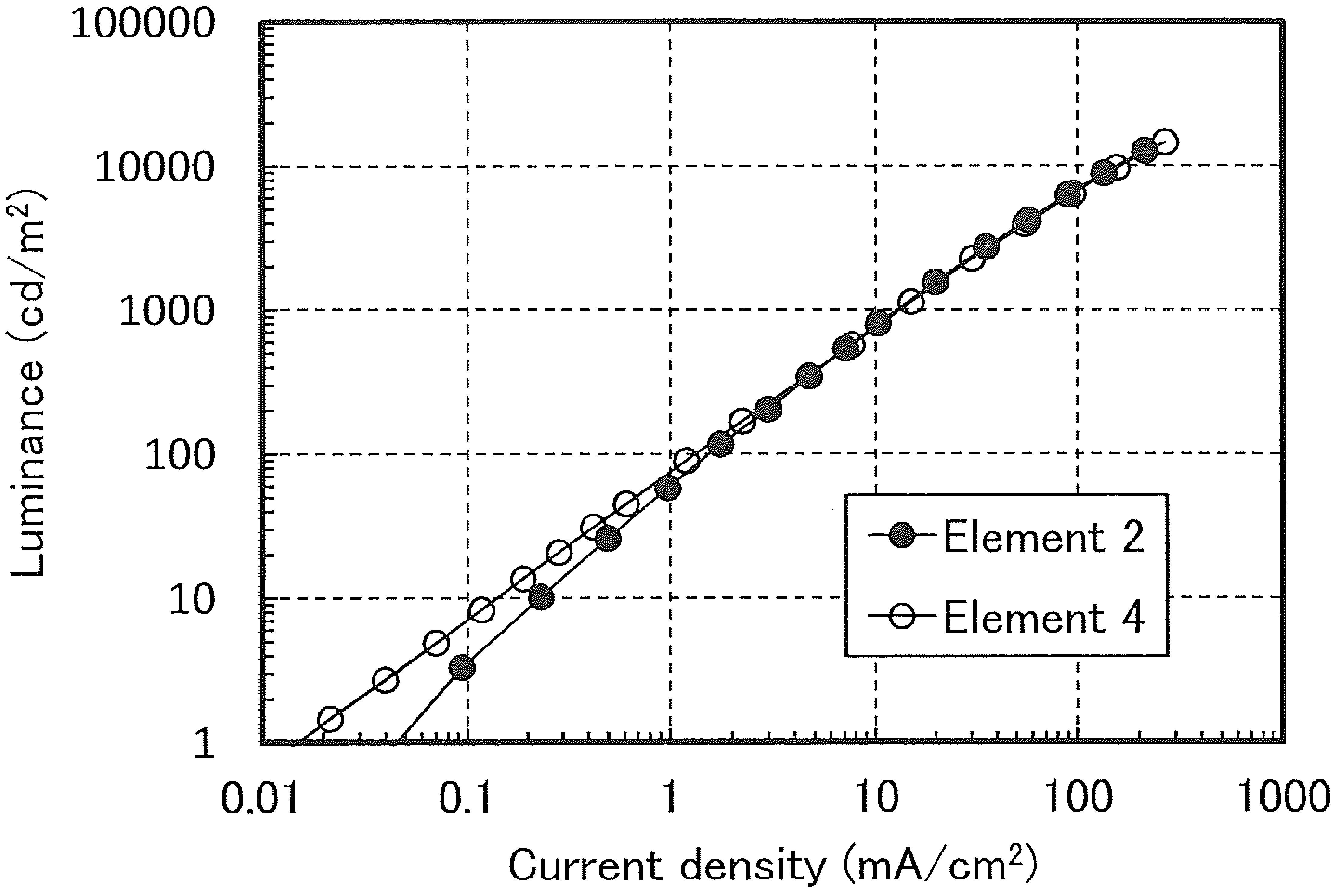

100000
10000
1000
100
10
1
Luminance (cd/m²)
0.01
0.1
1
10
100
1000
Current density (mA/cm²)
Element 2
Element 4

FIG. 25

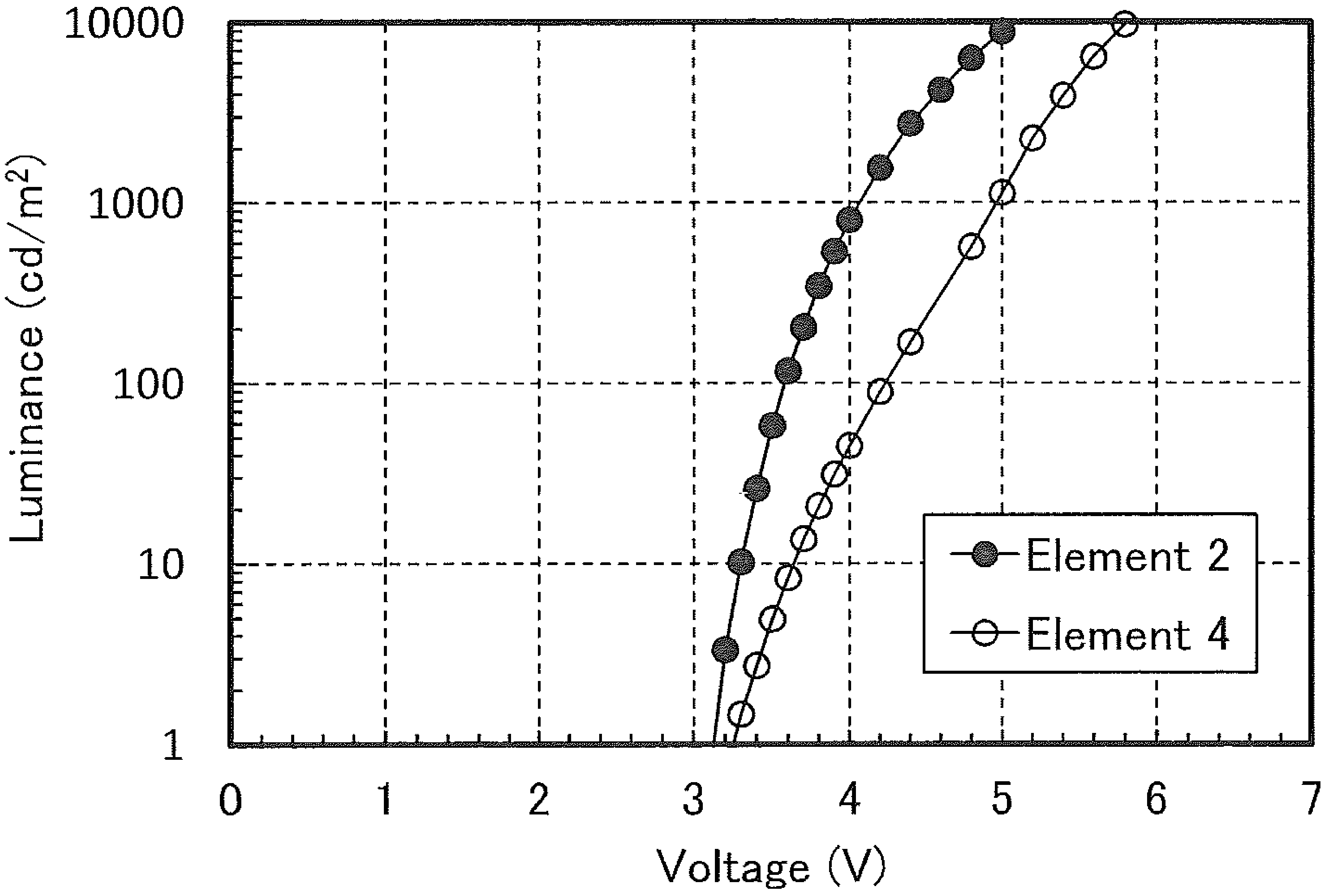

10000
1000
100
10
1
Luminance (cd/m²)
0
1
2
3
4
5
6
7
Voltage (V)
Element 2
Element 4

FIG. 26

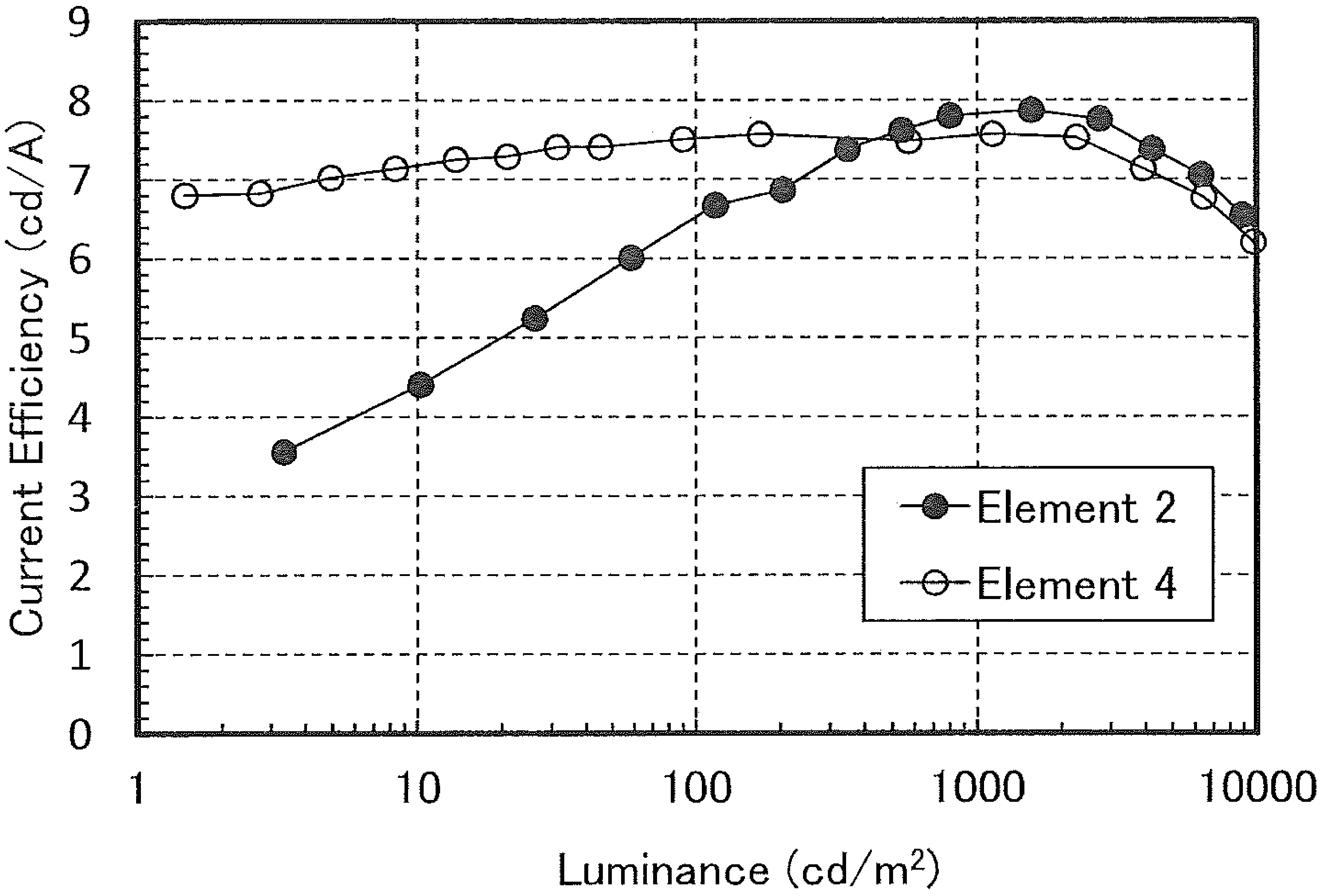

Current Efficiency (cd/A)
0
1
2
3
4
5
6
7
8
9
Luminance (cd/m²)
1
10
100
1000
10000
Element 2
Element 4

FIG. 27

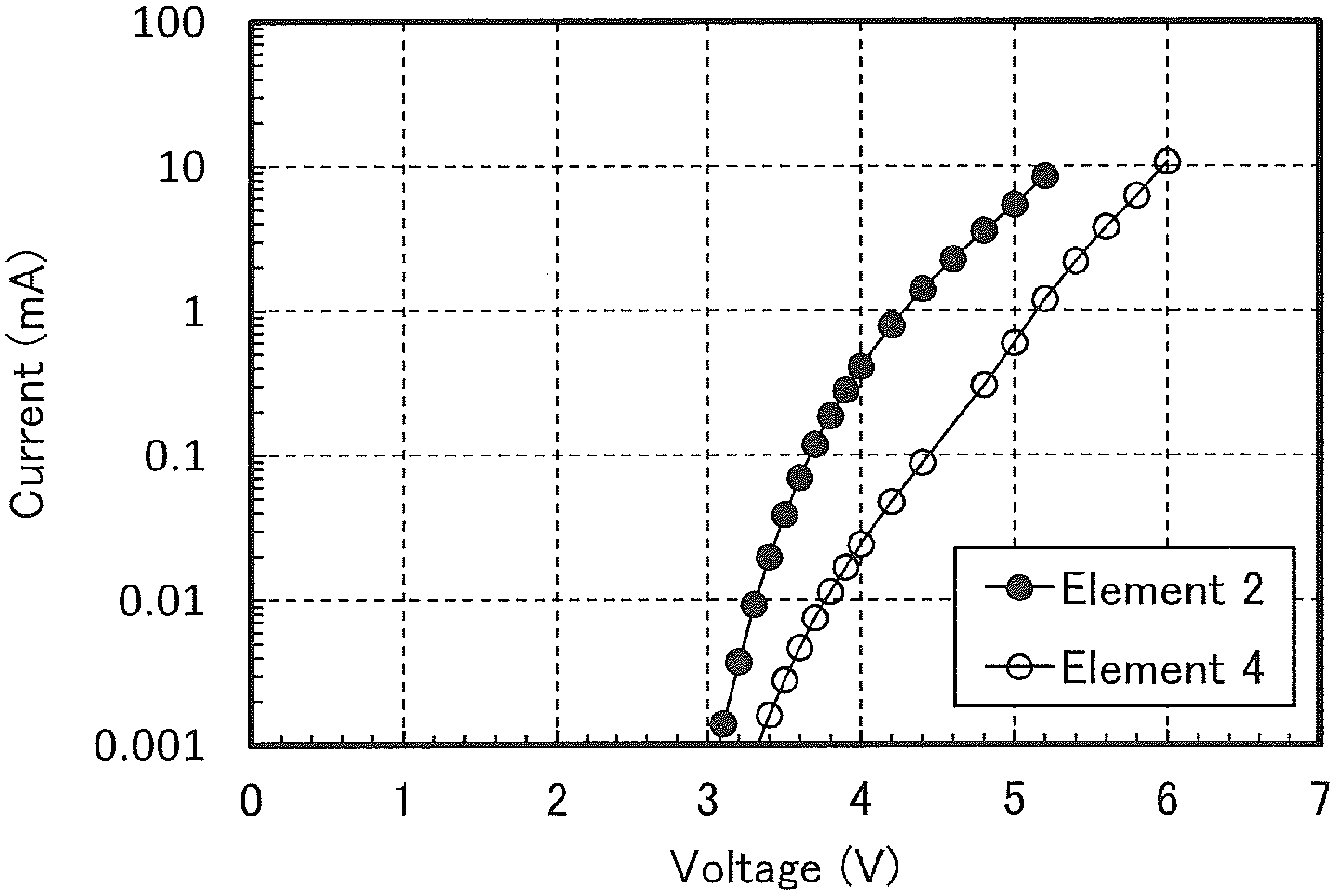

Current (mA)
0.001
0.01
0.1
1
10
100
Voltage (V)
0
1
2
3
4
5
6
7
Element 2
Element 4

FIG. 28

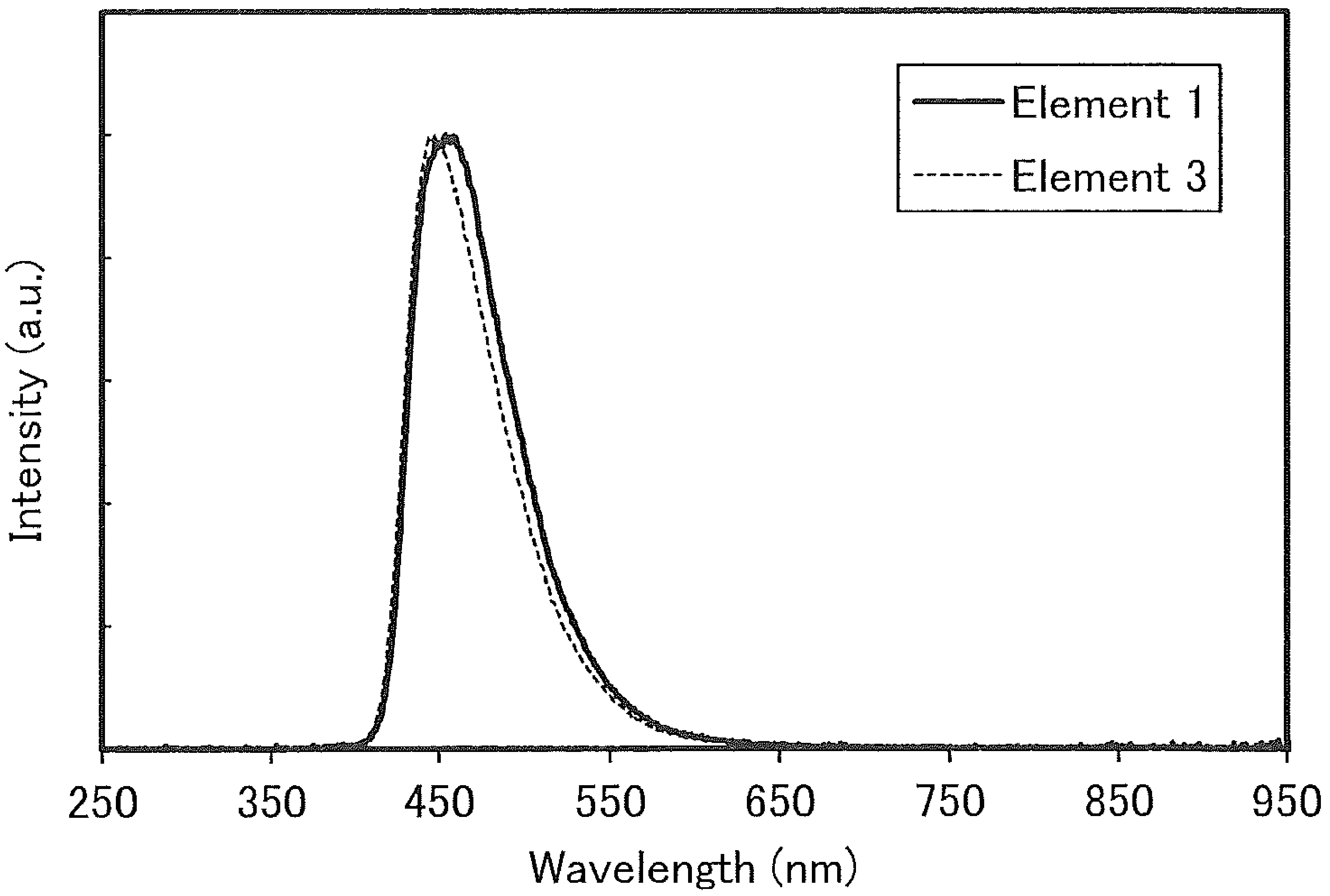
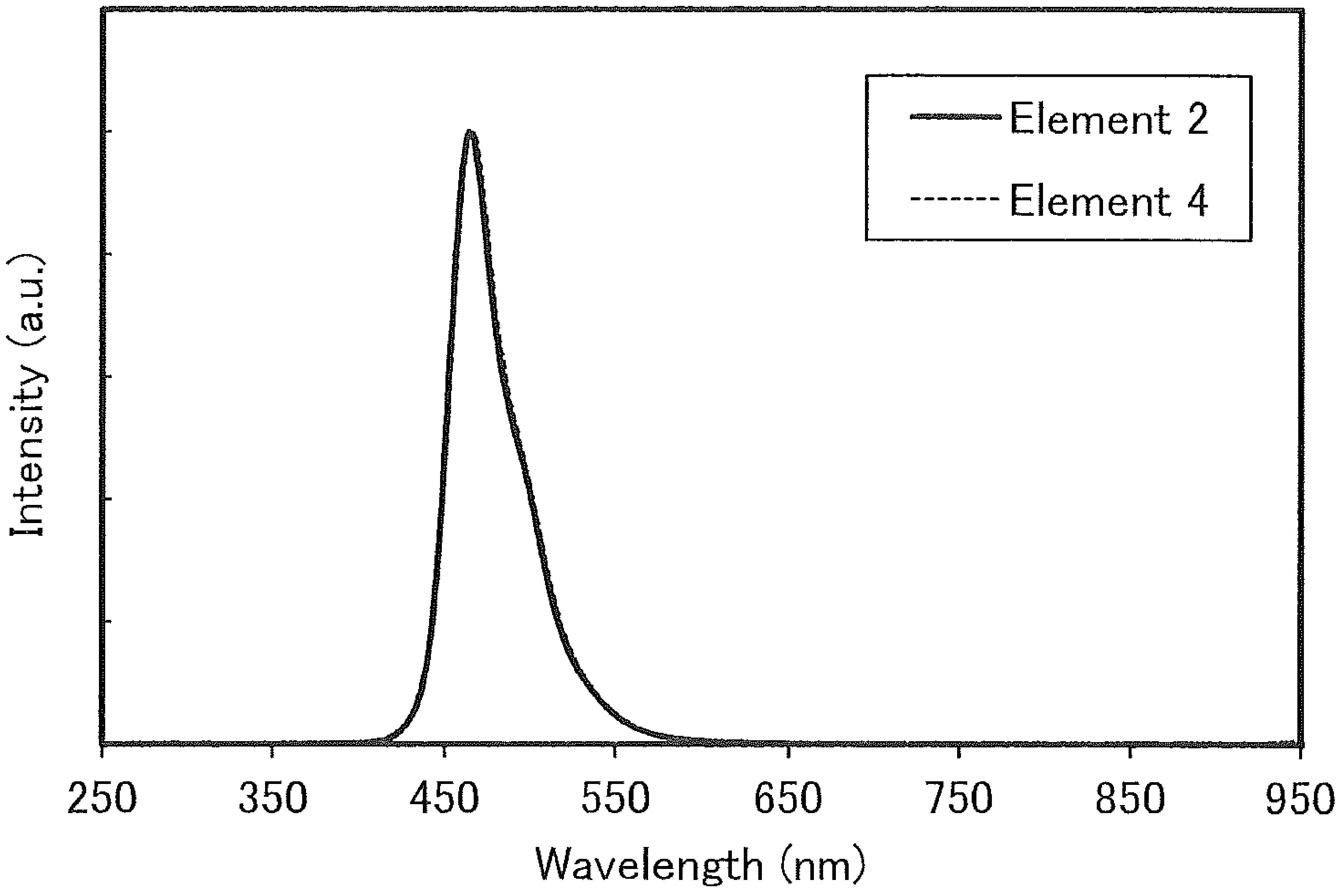

Element 1
Element 3
Intensity (a.u.)
250
350
450
550
650
750
850
950
Wavelength (nm)

FIG. 29



Element 2
Element 4
Intensity (a.u.)
250
350
450
550
650
750
850
950
Wavelength (nm)

FIG. 30A

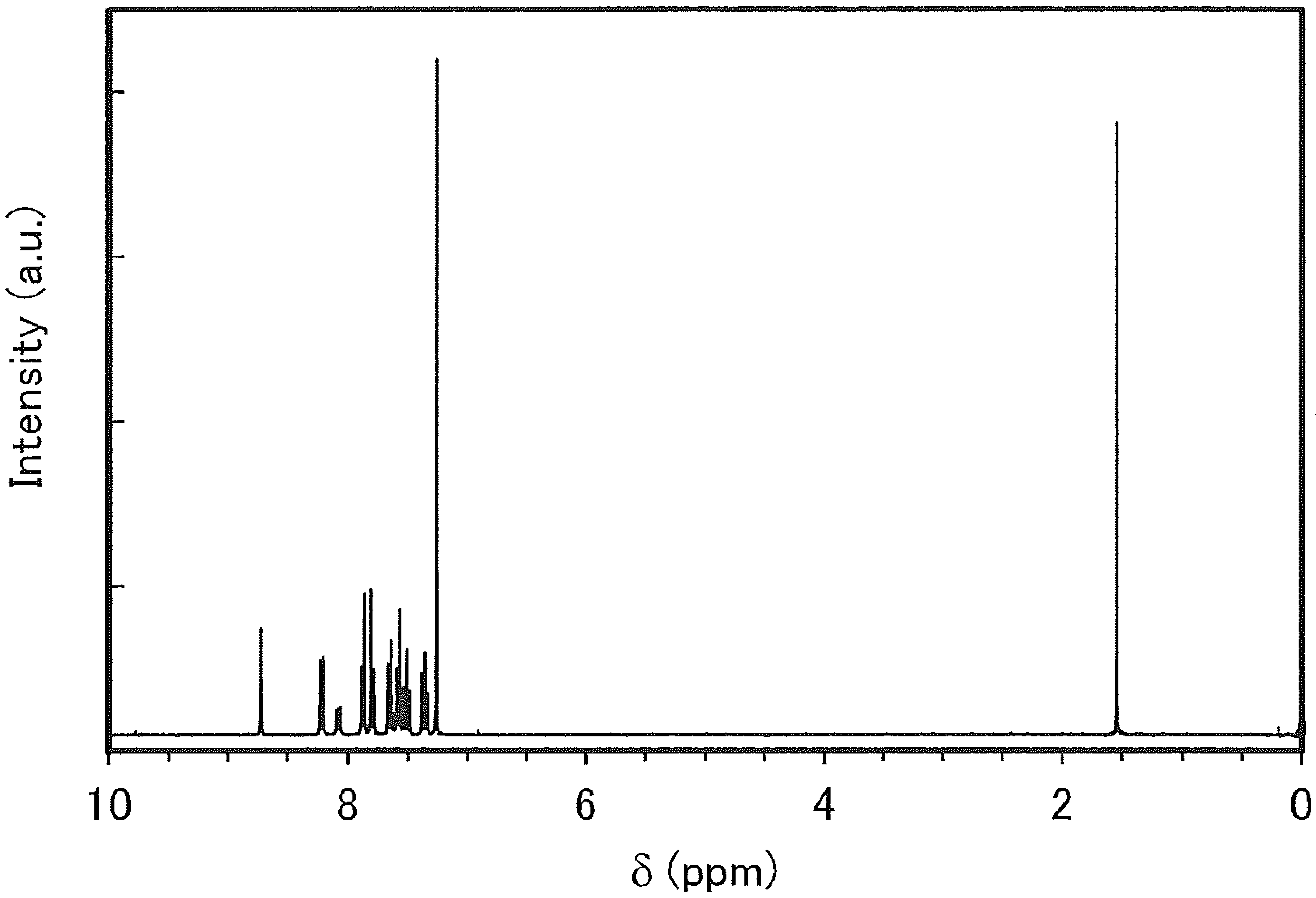


FIG. 30B

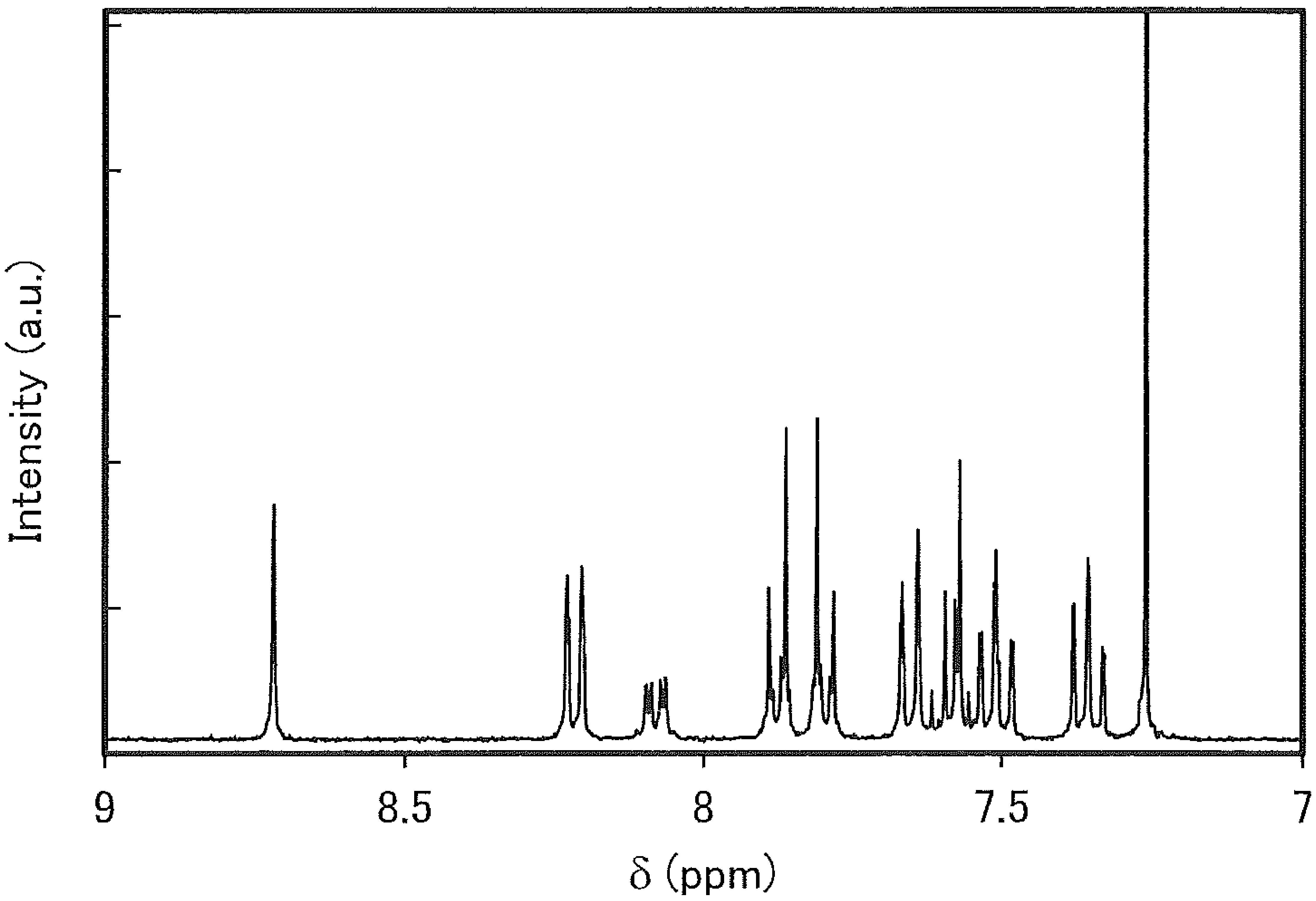


FIG. 31A

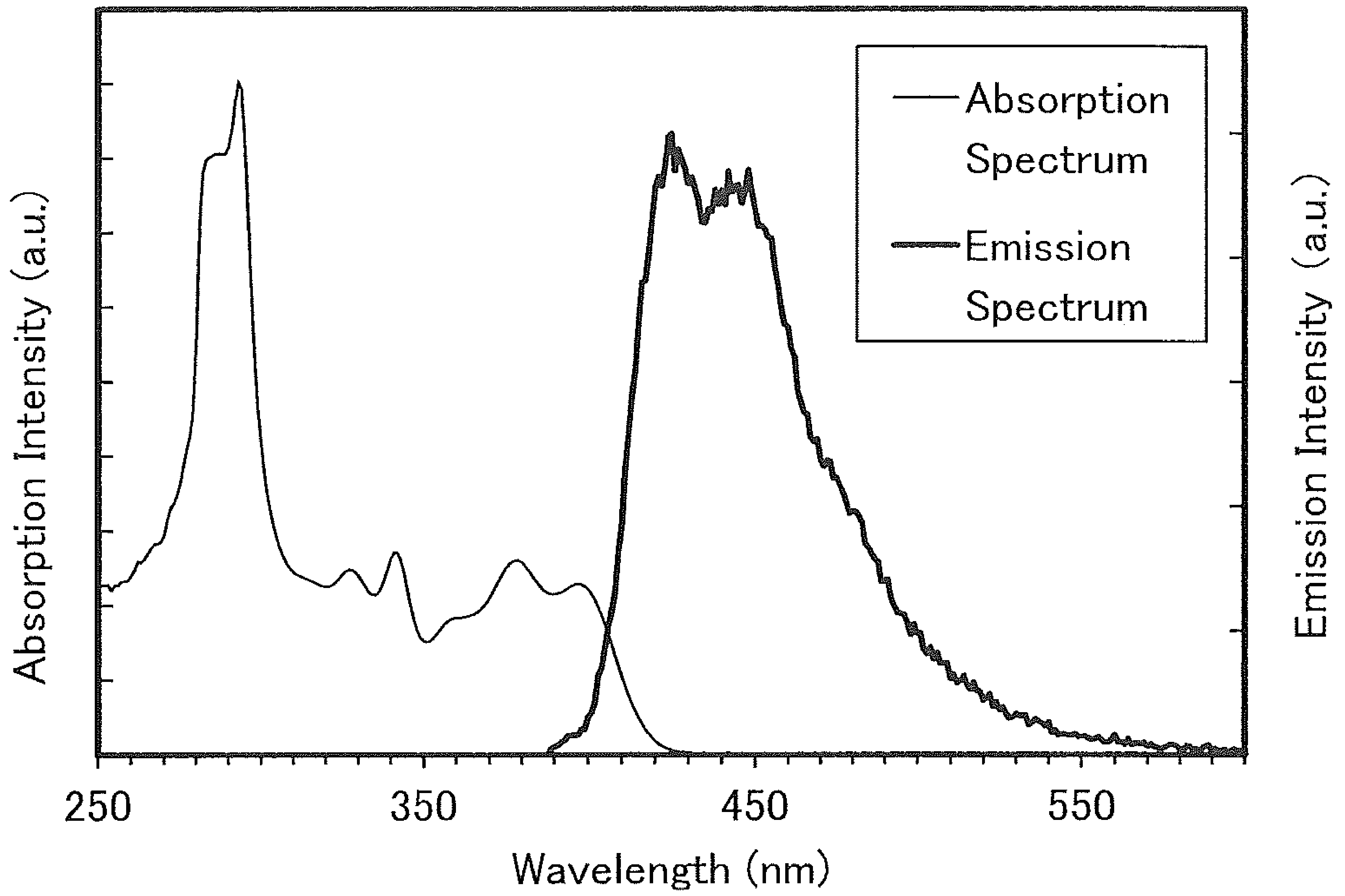


FIG. 31B

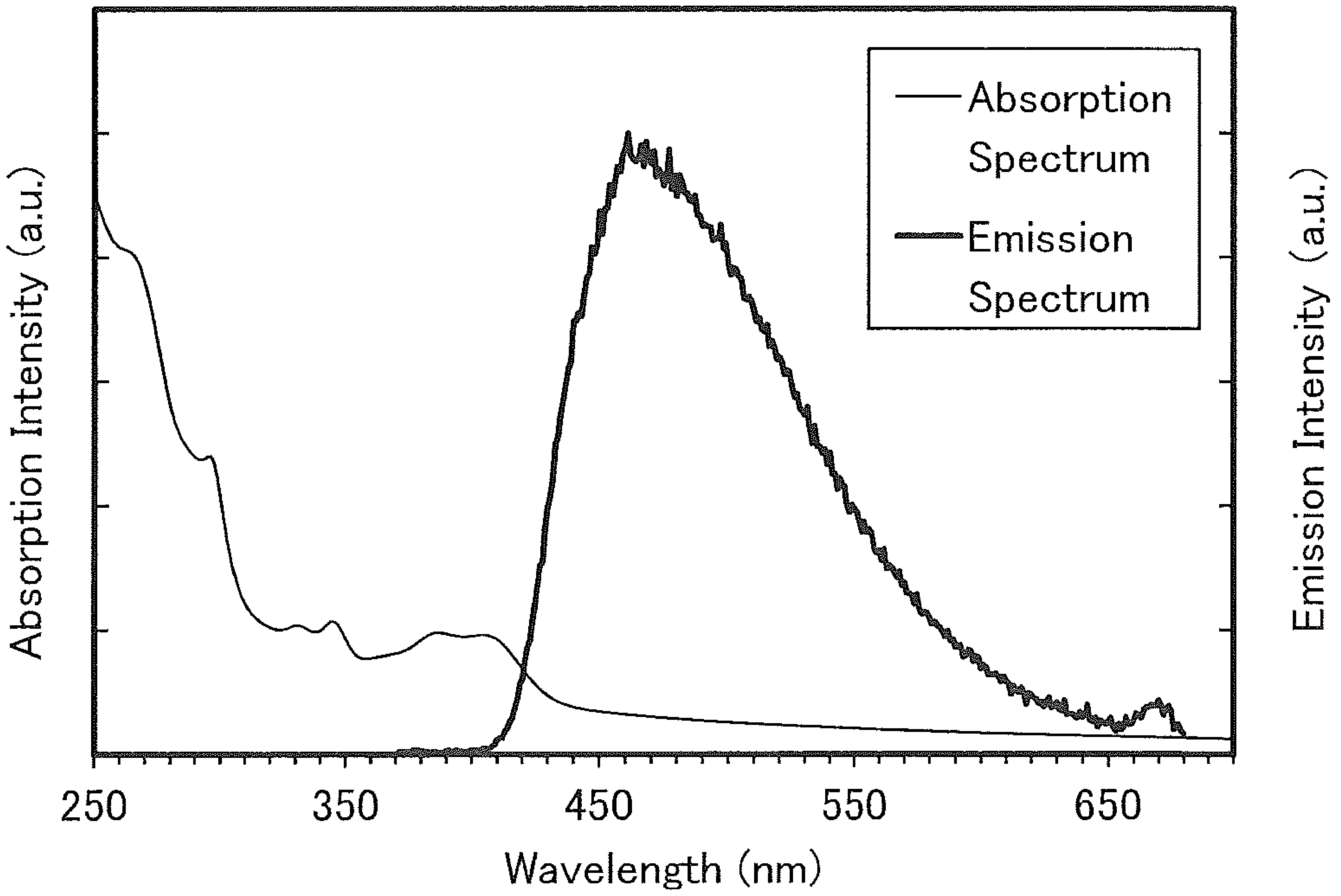


FIG. 32

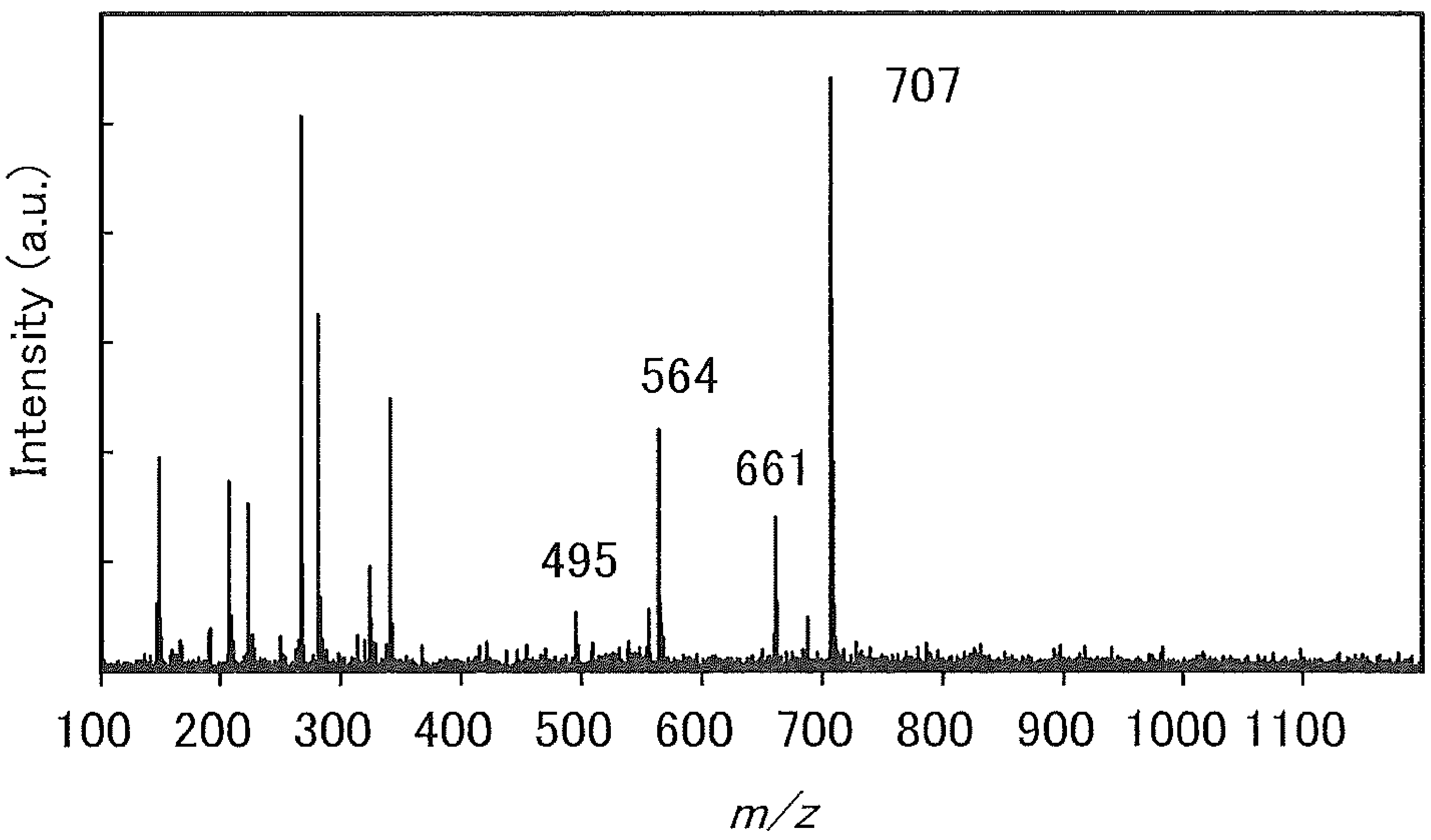

707
564
661
495
Intensity (a.u.)
100 200 300 400 500 600 700 800 900 1000 1100
m/z

FIG. 33A

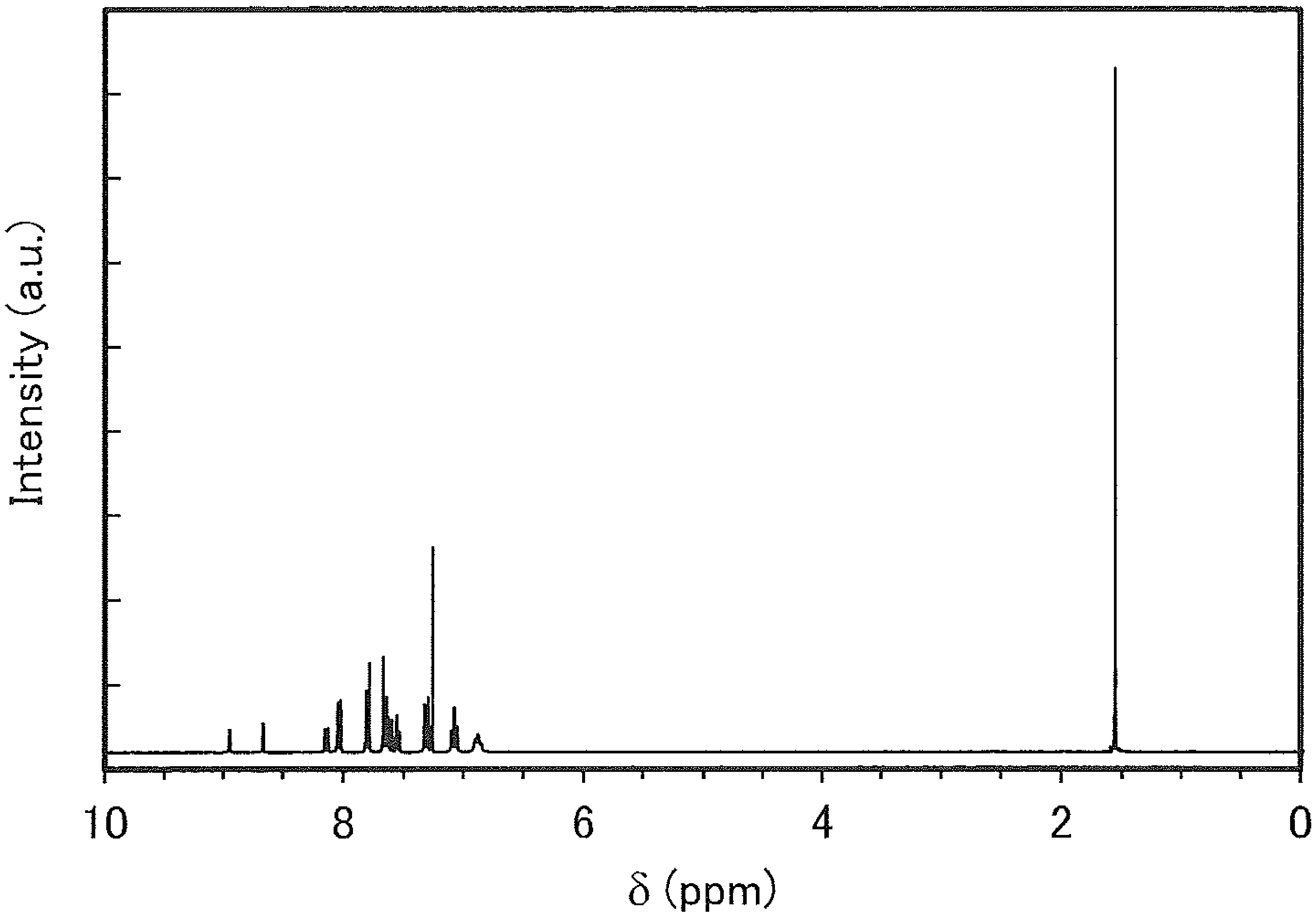


FIG. 33B

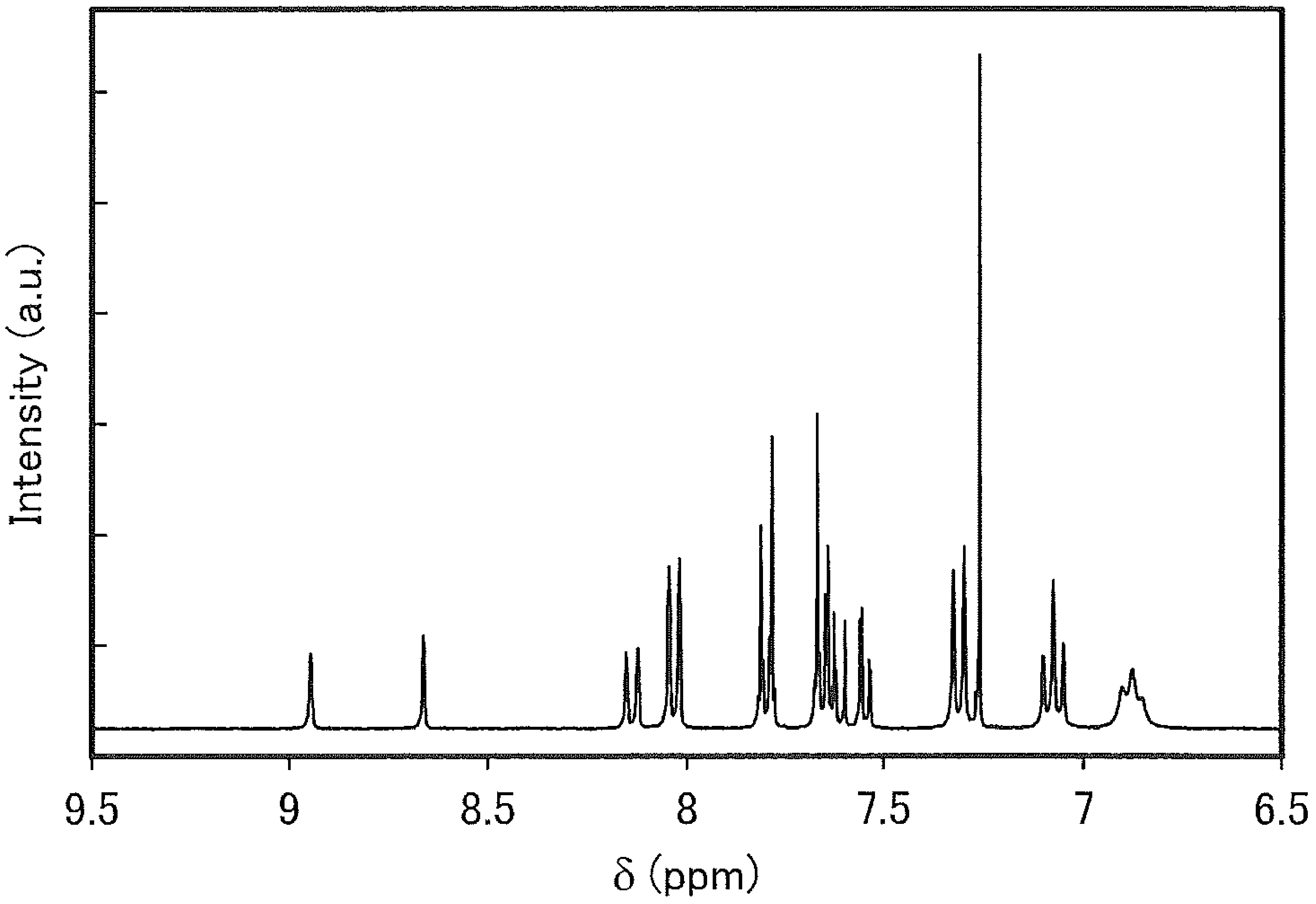


FIG. 34A

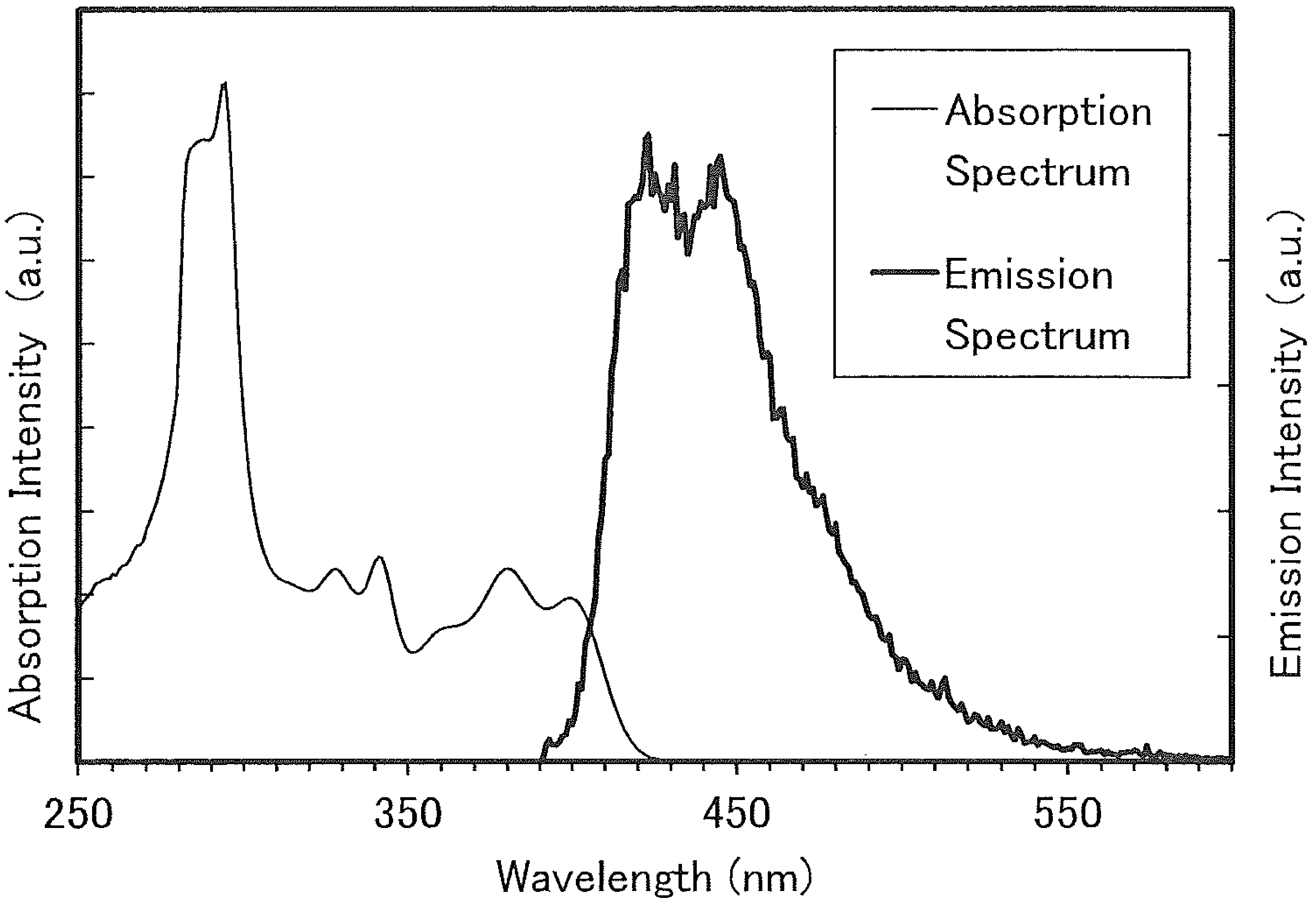


FIG. 34B

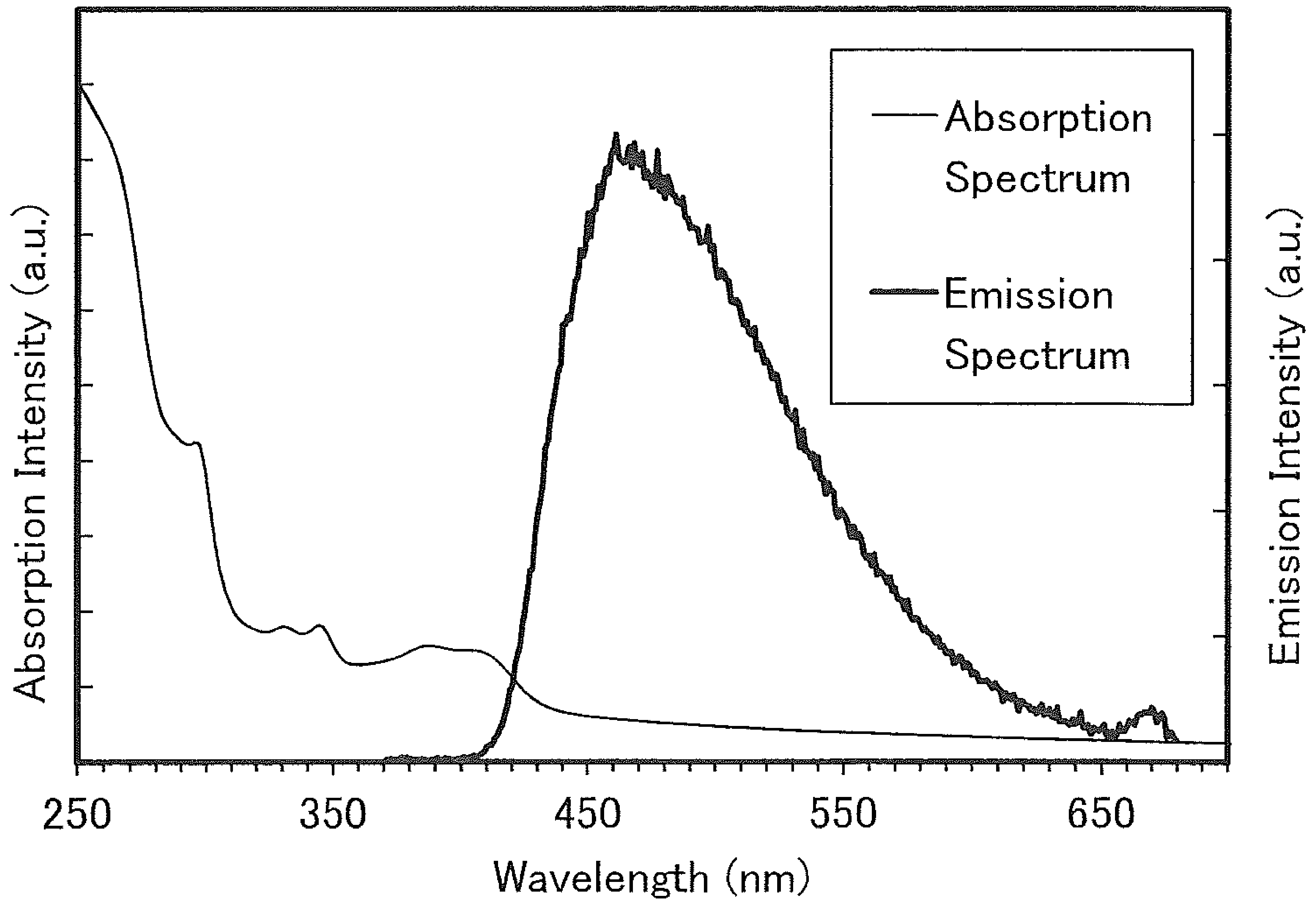


FIG. 35

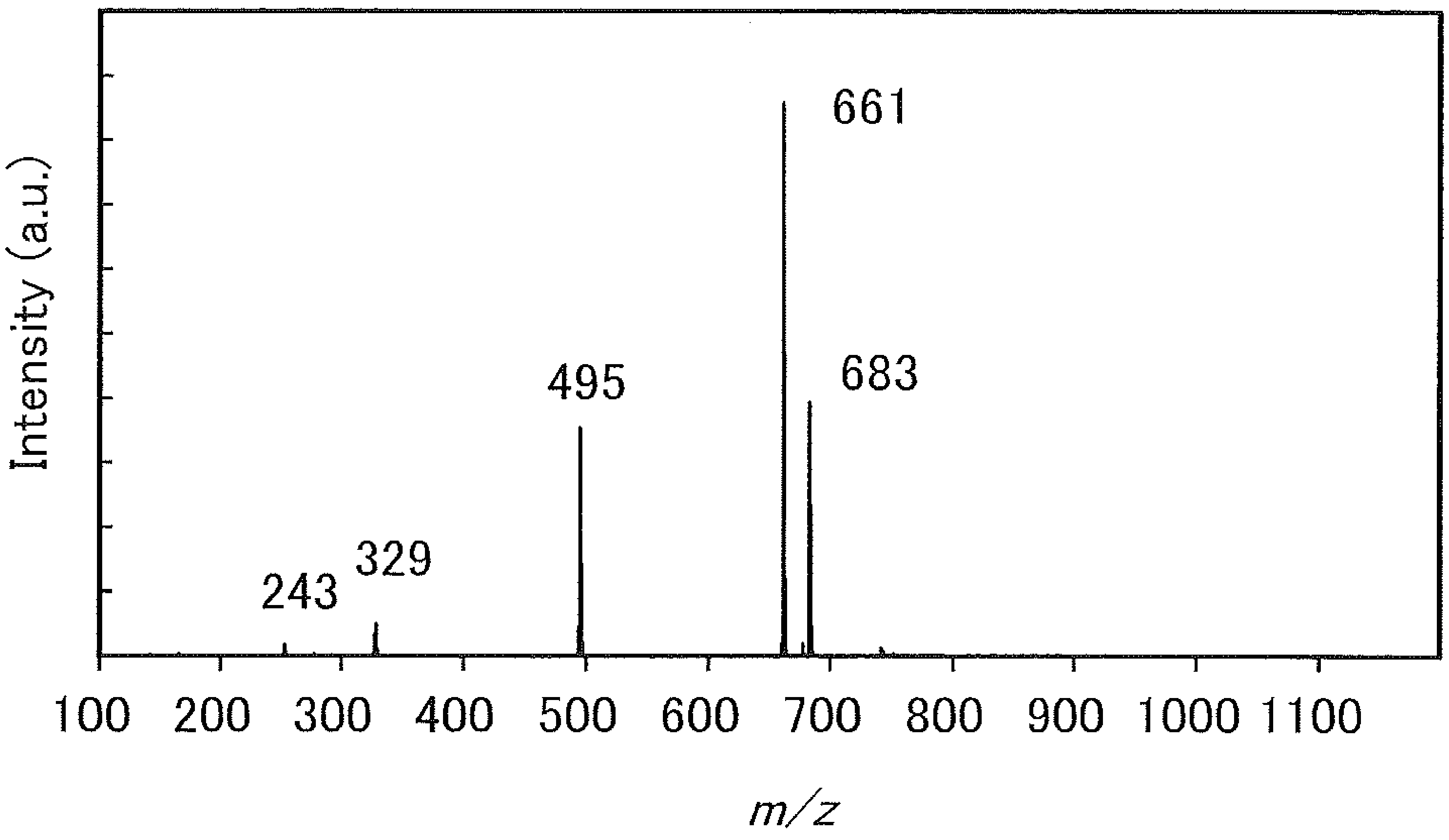

661
683
495
329
243
Intensity (a.u.)
100
200
300
400
500
600
700
800
900
1000
1100
m/z

FIG. 36A

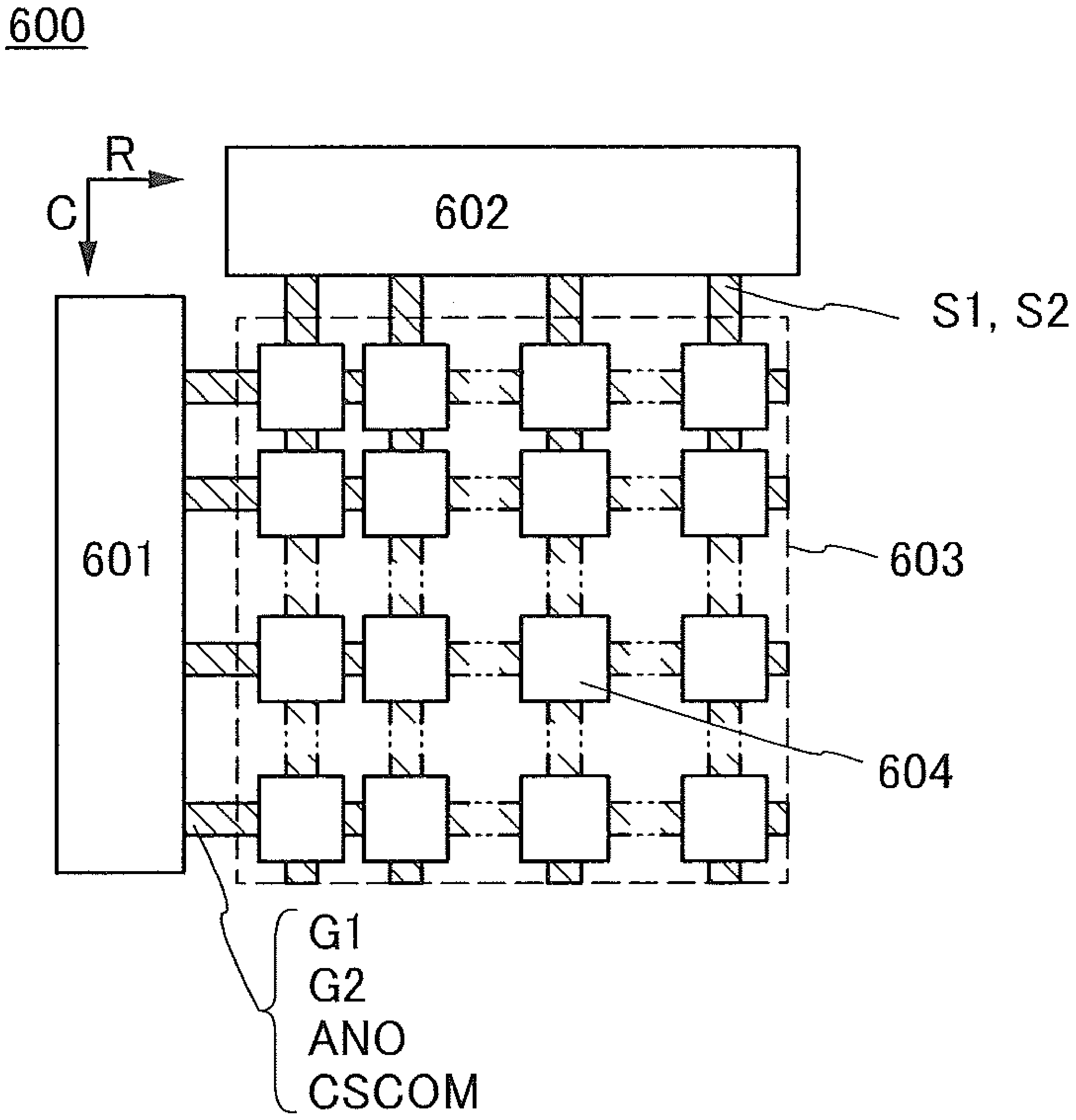


FIG. 36B1

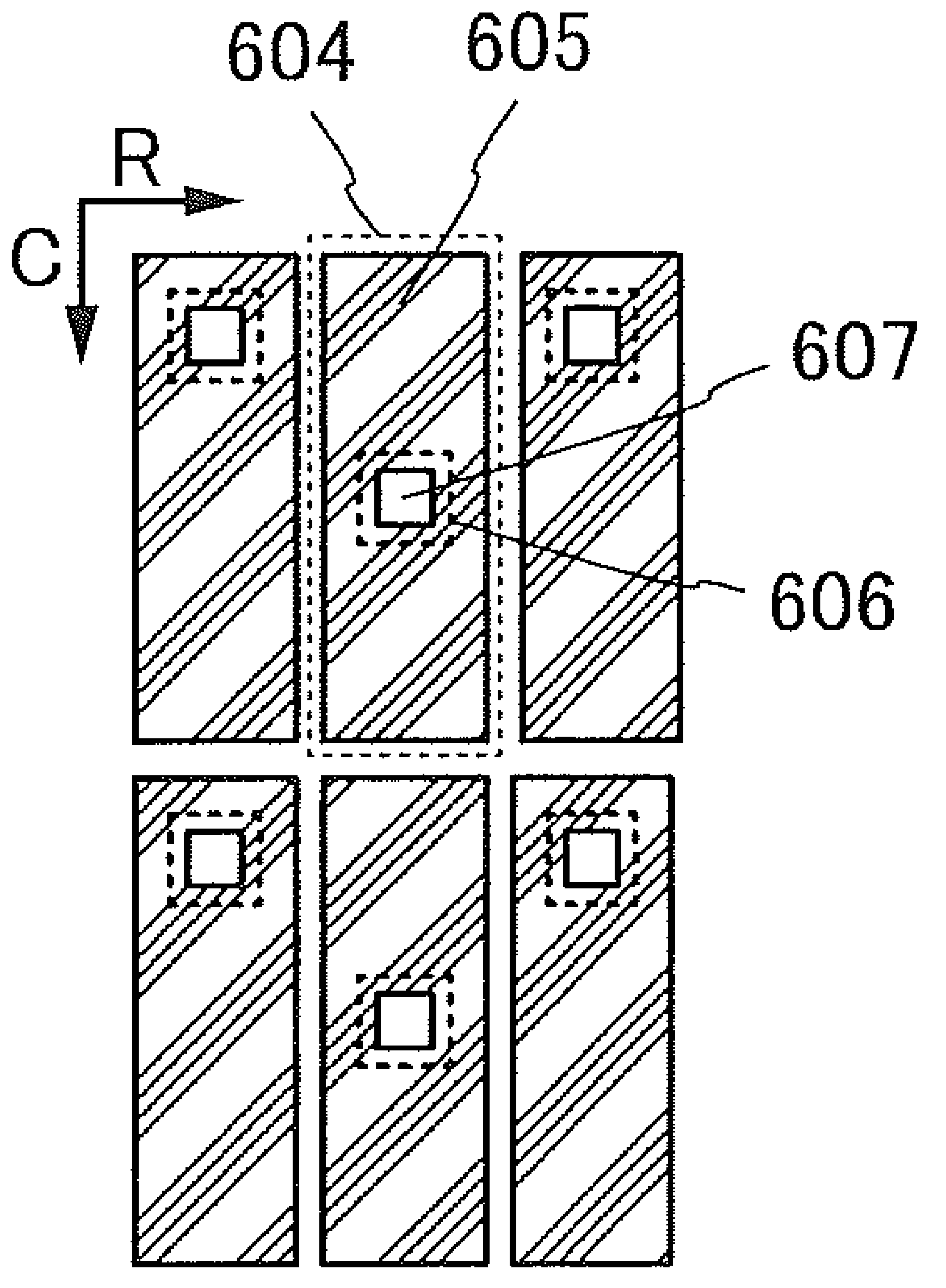


FIG. 36B2

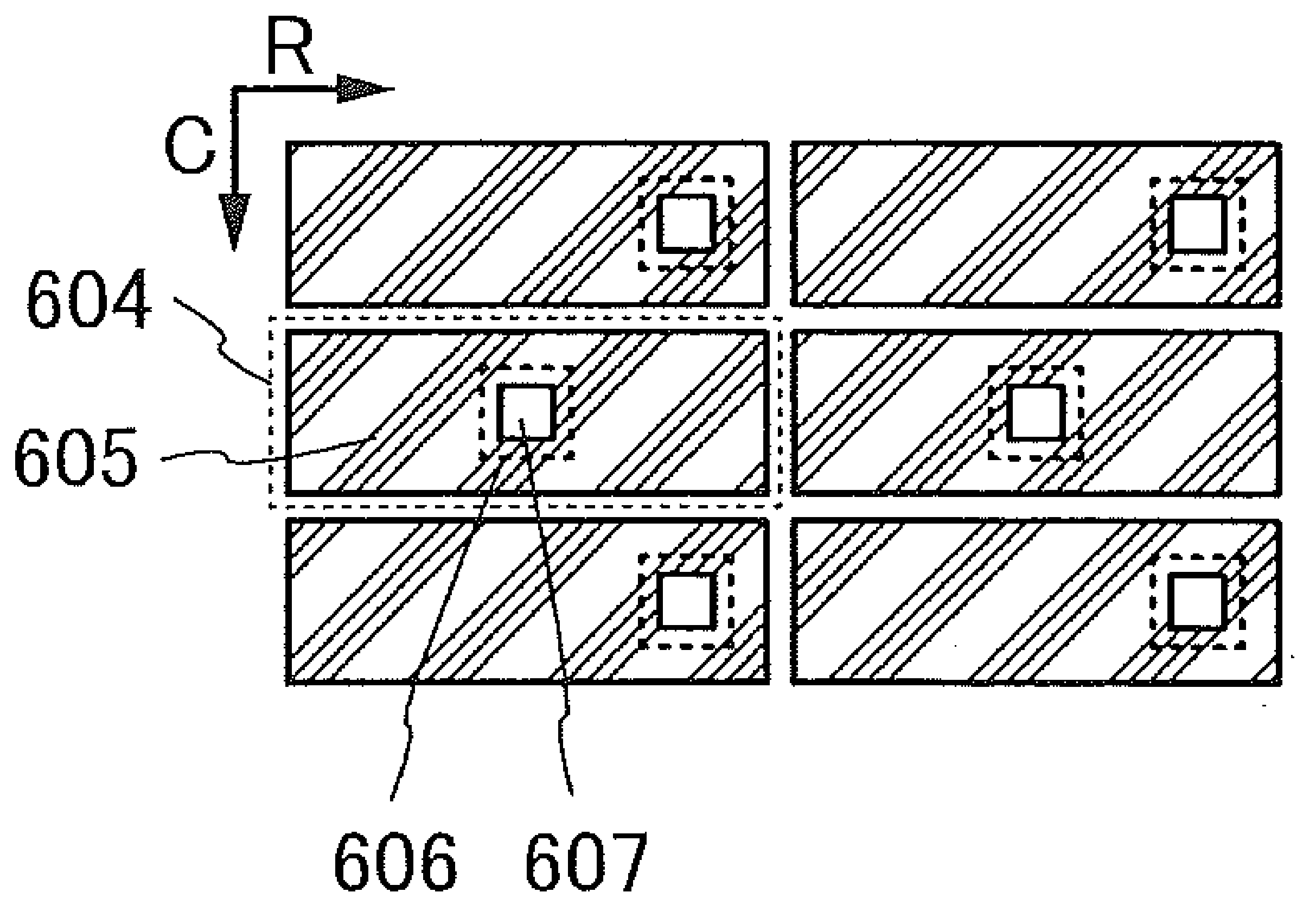


FIG. 37

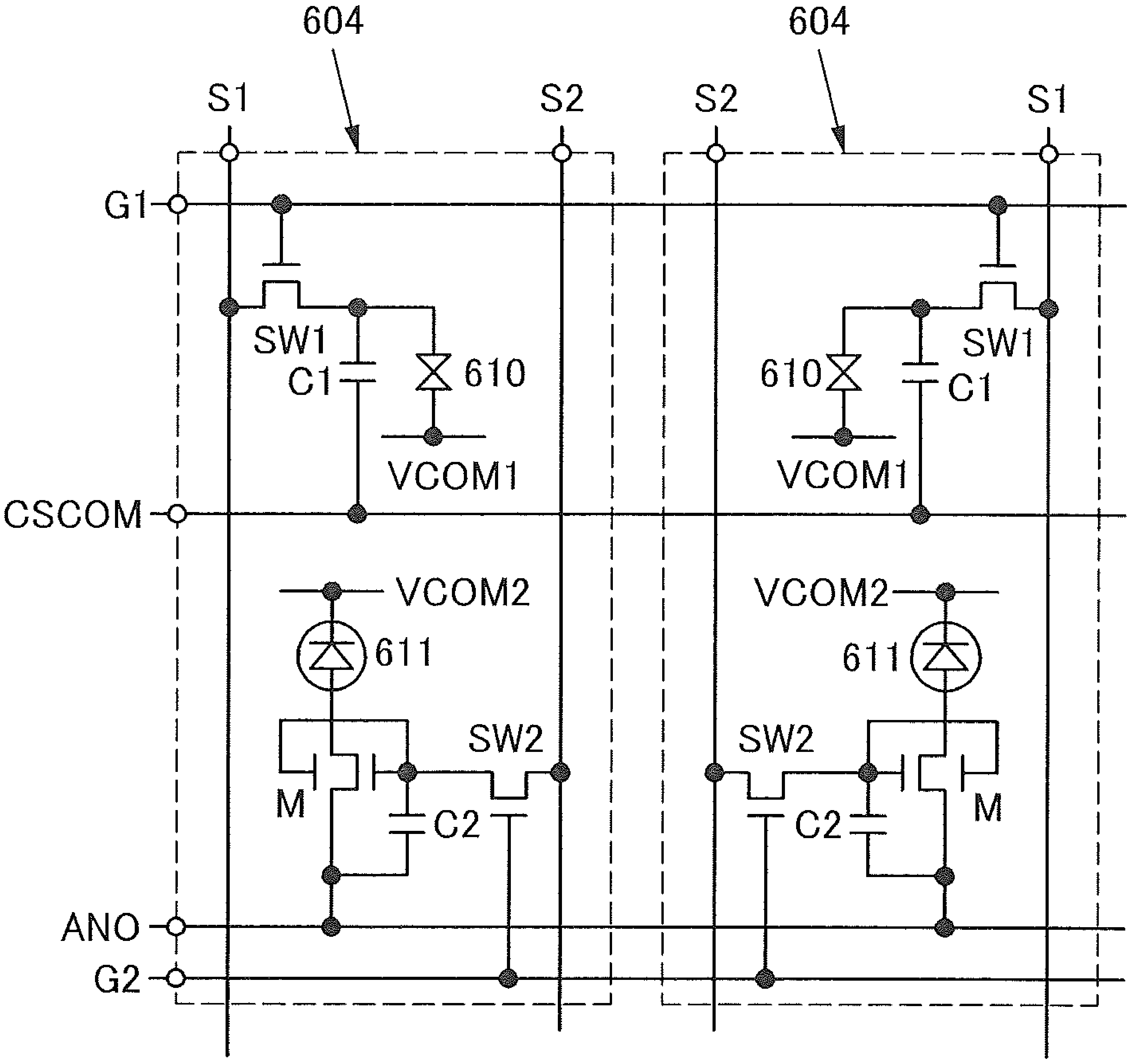

604
604
S1
S2
S2
S1
G1
SW1
C1
610
VCOM1
610
SW1
C1
VCOM1
CSCOM
VCOM2
611
VCOM2
611
SW2
M
C2
SW2
C2
M
ANO
G2

FIG 38

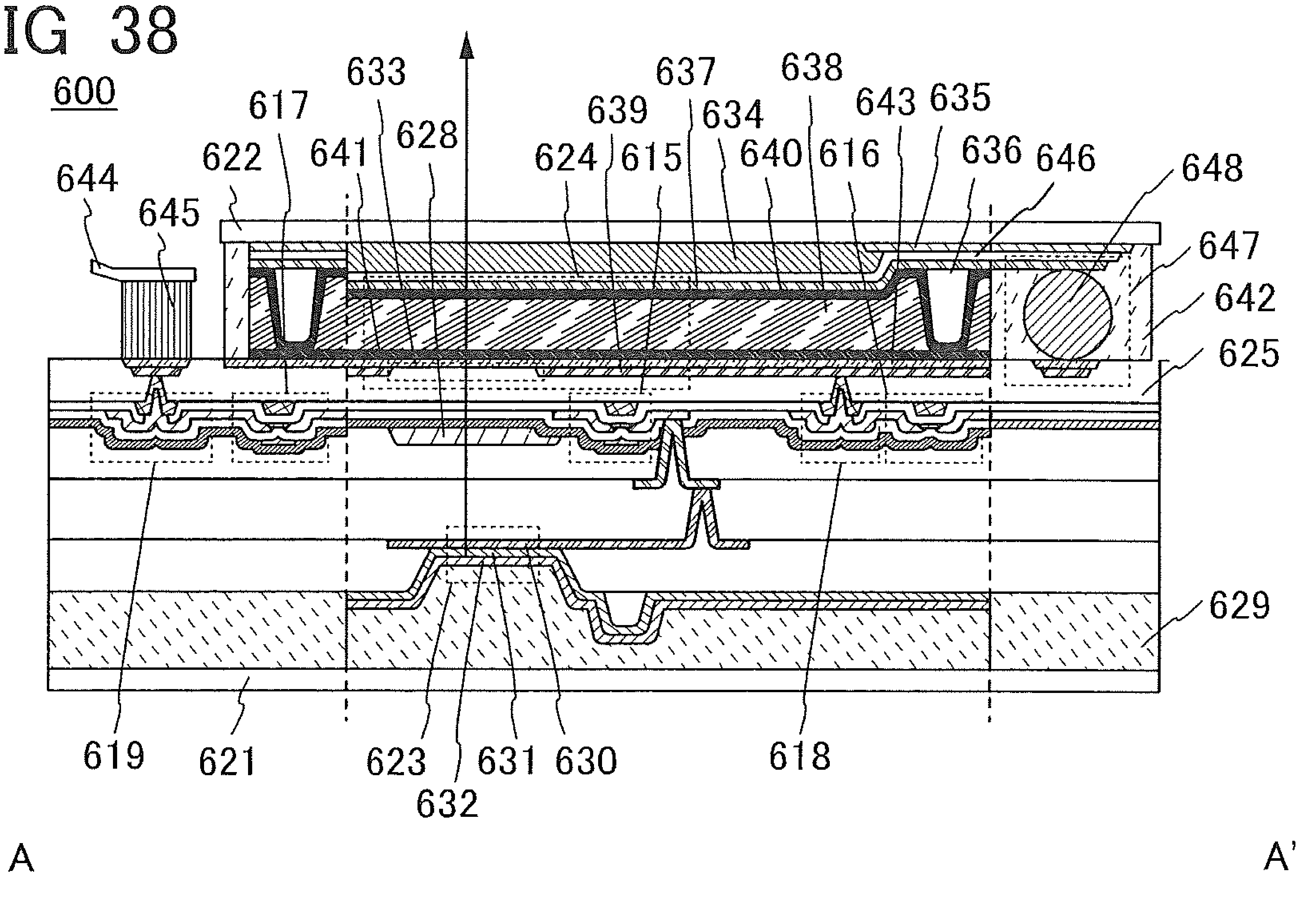

600
644
645
622
617
641
633
628
624
639
615
637
634
640
638
616
643
635
636
646
648
647
642
625
629
619
621
623
632
631
630
618
A
A'

FIG. 39A

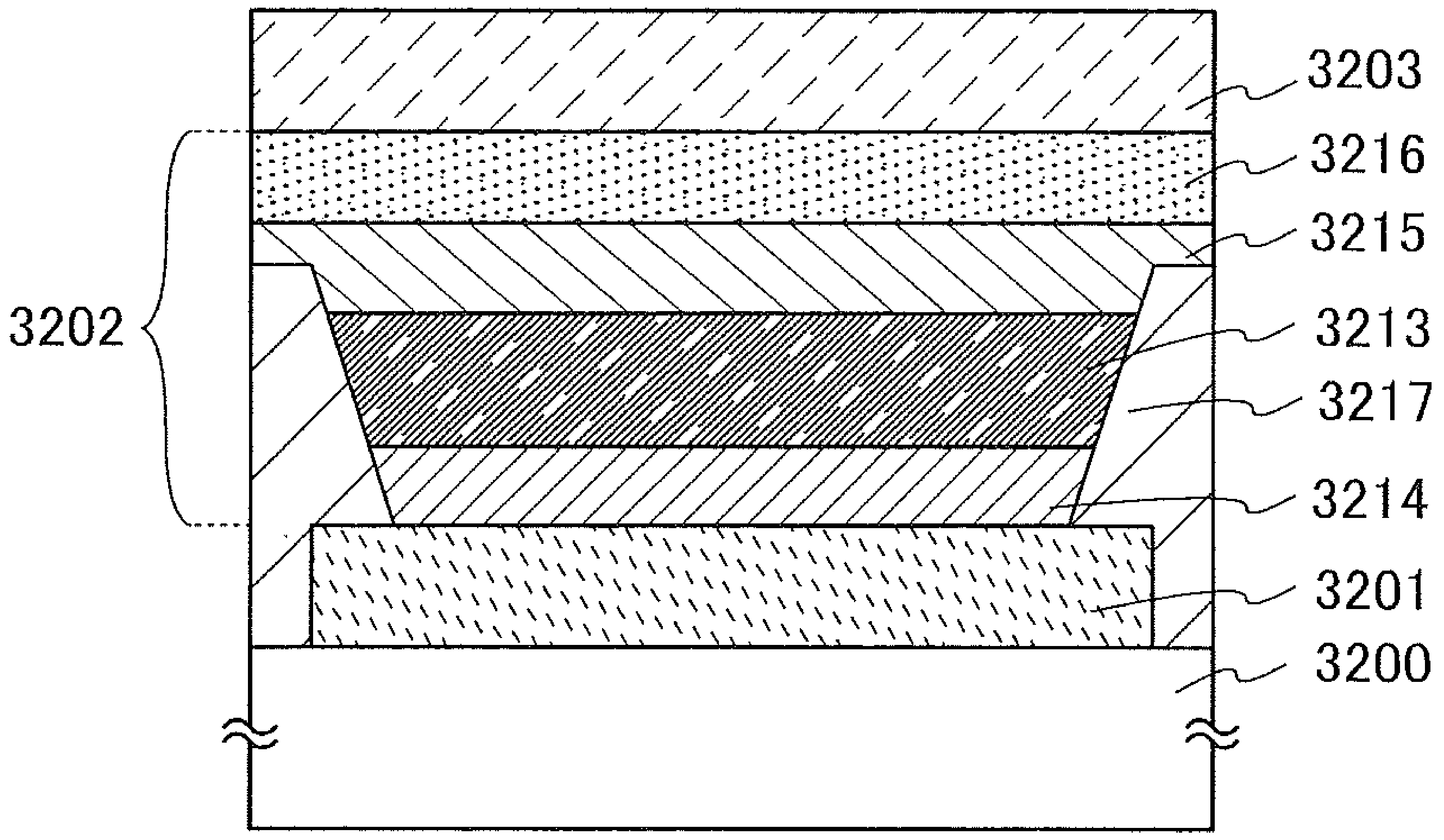


FIG. 39B

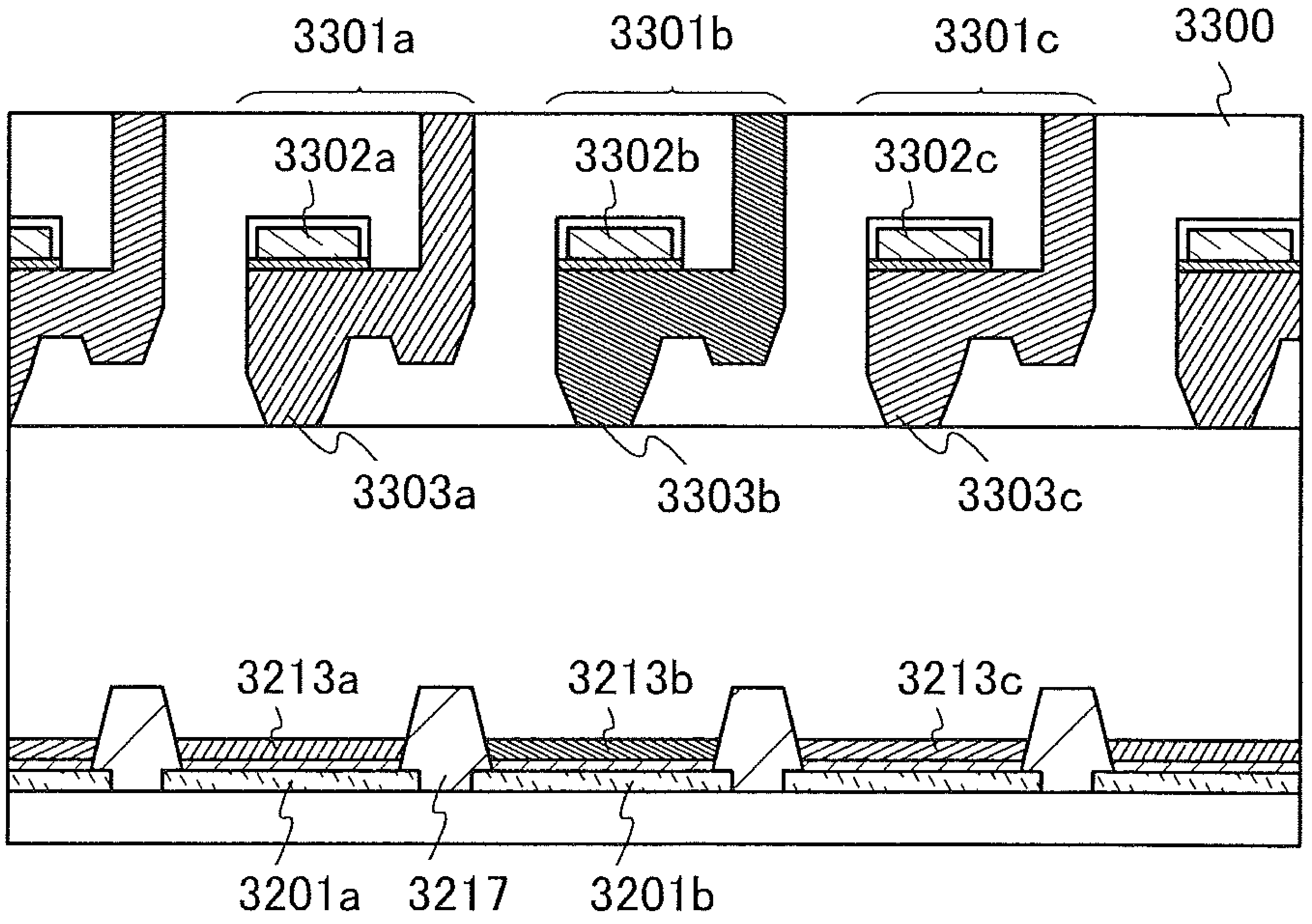
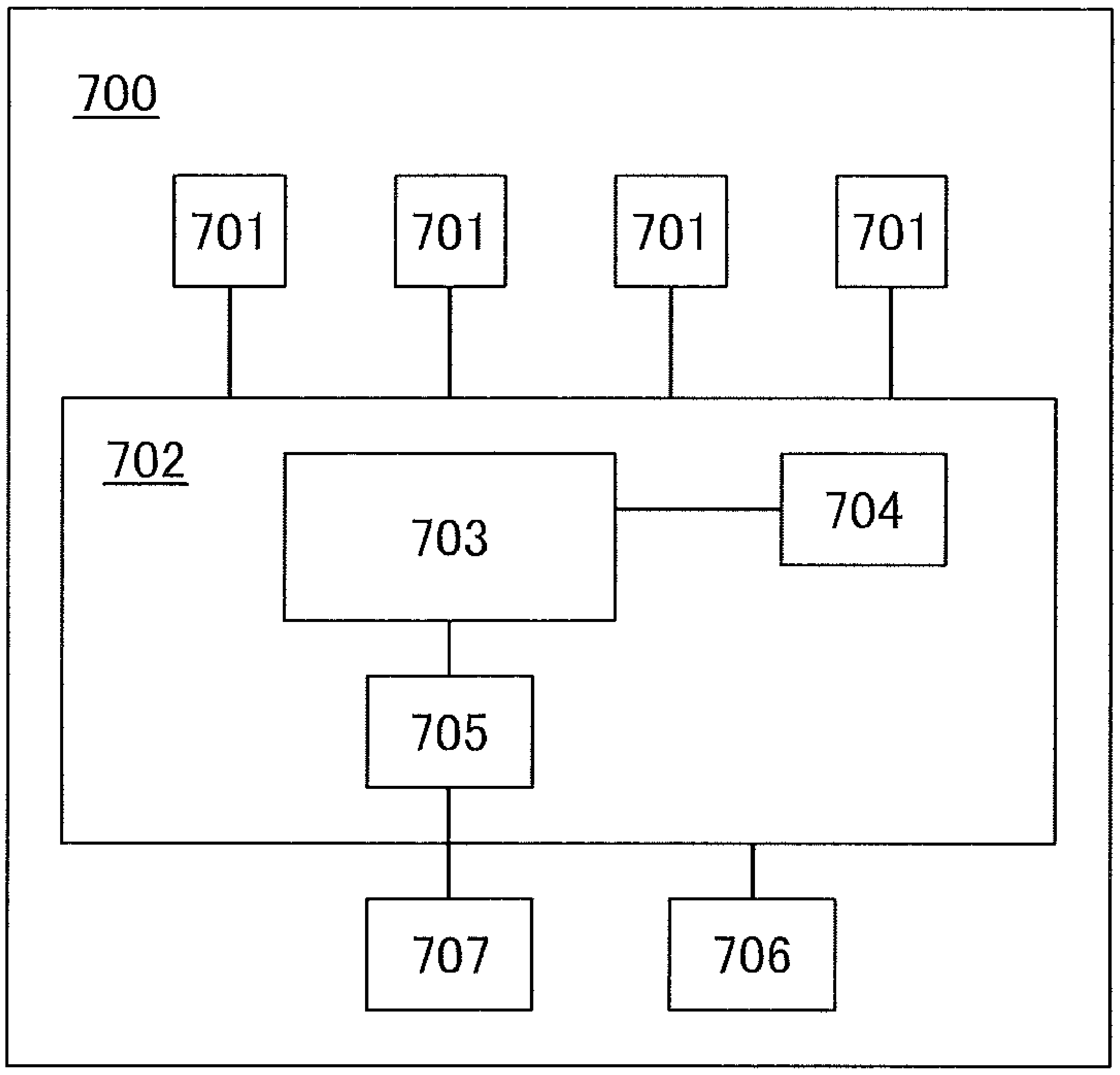


FIG. 40



LIGHT-EMITTING ELEMENT, LIGHT-EMITTING DEVICE, ELECTRONIC DEVICE, LIGHTING DEVICE, AND LIGHTING SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

One embodiment of the present invention relates to a light-emitting element, a light-emitting device, an electronic device, and a lighting device. In addition, one embodiment of the present invention relates to a lighting system. Note that one embodiment of the present invention is not limited to the above technical field. The technical field of one embodiment of the invention disclosed in this specification and the like relates to an object, a method, or a manufacturing method. In addition, one embodiment of the present invention relates to a process, a machine, manufacture, or a composition of matter. Specifically, examples of the technical field of one embodiment of the present invention disclosed in this specification include a semiconductor device, a display device, a liquid crystal display device, a light-emitting device, a power storage device, a storage device, a method for driving any of them, and a method for manufacturing any of them.

2. Description of the Related Art

In recent years, research and development of light-emitting elements using electroluminescence (EL) have been actively conducted. In a basic structure of such a light-emitting element, a layer containing a light-emitting substance (an EL layer) is interposed between a pair of electrodes. By applying a voltage between the pair of electrodes of this element, light emission from the light-emitting substance can be obtained.

Since the above light-emitting element is a self-luminous type, a display device using this light-emitting element has advantages such as high visibility, no necessity of a backlight, and low power consumption. Further, such a light-emitting element also has advantages in that the element can be formed to be thin and lightweight, and that response time is high.

It is said that the light emission mechanism of a light-emitting element is as follows: when a voltage is applied between a pair of electrodes with an EL layer including a light-emitting substance provided therebetween, electrons injected from a cathode and holes injected from an anode recombine in the light emission center of the EL layer to form molecular excitons, and energy is released and light is emitted when the molecular excitons relax to the ground state.

The excited states of an organic compound in which molecular excitons are formed include a singlet excited state (S*) and a triplet excited state (T*), and light emission from the singlet excited state is referred to as fluorescence, and light emission from the triplet excited state is referred to as phosphorescence. The statistical generation ratio thereof in the light-emitting element is considered to be S*:T*=1:3. In other words, a light-emitting element containing a compound emitting phosphorescence has higher emission efficiency than a light-emitting element containing a compound emitting fluorescence. Therefore, light-emitting elements containing phosphorescent compounds capable of converting a triplet excited state into light emission has been actively developed in recent years.

Among light-emitting elements containing phosphorescent compounds, in particular, a light-emitting element that emits blue light has not yet been put into practical use because it is difficult to develop a stable compound having a high triplet excited energy level. For this reason, the development of a light-emitting element containing a more stable fluorescent compound has been conducted and high efficiency of a light-emitting element containing a fluorescent compound (fluorescent light-emitting element) has been required.

In the light-emitting element containing a fluorescent compound, triplet-triplet annihilation (TTA) is known as a light emission mechanism capable of converting part of a triplet excited state into light emission. The term TTA refers to a process in which, when two triplet excitons approach each other, excited energy and spin angular momentum are exchanged and transferred to form singlet excitons.

As a compound in which TTA occurs, a compound including an anthracene skeleton is known. Non-Patent Document 1 discloses that the use of a compound including an anthracene skeleton as a host material achieves high external quantum efficiency in a light-emitting element that emits blue light. It also discloses that the proportion of the delayed fluorescence due to TTA to the total light emitted from the light-emitting element using a compound including an anthracene skeleton is approximately 10%.

PATENT DOCUMENT

Non-Patent Document

[Non-Patent Document 1]

Tsunenori Suzuki et al., Japanese Journal of Applied Physics, Vol. 53, 052102 (2014)

SUMMARY OF THE INVENTION

One embodiment of the present invention is to provide a light-emitting element which contains a fluorescent compound and has high efficiency. Another embodiment of the present invention is to provide a light-emitting element in which the proportion of delayed fluorescence to the total light emitted from the light-emitting element is higher than that in a conventional light-emitting element. Another embodiment of the present invention is to provide a novel light-emitting element. Another embodiment of the present invention is to provide a novel light-emitting device. Another embodiment of the present invention is to provide a novel light-emitting device, a novel electronic device, or a novel lighting device. Another embodiment of the present invention is to provide a lighting system in which energy saving of a light-emitting element that is a light source is achieved. Note that the description of the object does not disturb the existence of other objects. In one embodiment of the present invention, there is no need to achieve all the objects. Other objects will be apparent from and can be derived from the description of the specification, the drawings, the claims, and the like.

According to one embodiment of the present invention, emission efficiency of a light-emitting element containing a fluorescent compound can be improved by increasing the probability of TTA caused by an organic compound in an EL layer, converting energy of triplet excitons, which does not contribute to light emission, into energy of singlet excitons, and making the fluorescent compound emit light by energy transfer of the singlet excitons.

As one of methods for efficiently converting the energy of triplet excitons into the energy of singlet excitons, energy transfer and intersystem crossing which are caused by the Förster mechanism are used. The Förster mechanism is a mechanism in which energy is transferred by resonance, which occurs more easily when the following conditions are satisfied: organic compounds (host materials) containing triplet excitons approach each other with an intermolecular distance of 1 nm to 10 nm, the oscillator strength for transition from the lowest triplet excited level (referred as a T_1 level) of the organic compound (host material) to one of levels of triplet excited states which are higher than the T_1 level of the organic compound (referred as T_n levels) is high (energy absorption in transition is high), and the like.

One embodiment of the present invention is to provide a light-emitting element in which energy transfer by the Förster mechanism is likely to occur so that the probability of TTA in an EL layer of a light-emitting element is increased.

One embodiment of the present invention is a light-emitting element including an EL layer between an anode and a cathode. The EL layer includes a light-emitting layer. The light-emitting layer comprises a first organic compound. A difference between the T_1 level of the first organic compound and one or more of T_n, levels of the first organic compound is less than the sum of the T_1 level and 0.6 eV. Note that the levels of triplet excited states which are higher than the T_1 level are referred to as T_n levels in this invention. That is, one or more of the T_n levels of the first organic compound preferably have an energy level close to twice the T_1 level of the first organic compound, because energy transfer from the T_1 level to the T_n levels is facilitated.

In the above structure, an energy difference between any one of the T_n levels of the first organic compound and any one of levels of singlet excited states of the first organic compound is 1 eV or less. Note that the levels of the singlet excited states of the first organic compound includes an S_1 level (the lowest singlet excited level) and S_n levels (levels that are higher than the S_1 level). This case is also preferable because intersystem crossing easily occurs as the energy level of any one of the T_n levels of the first organic compound is closer to that of any one of the S_1 level and the S_n levels of the first organic compound.

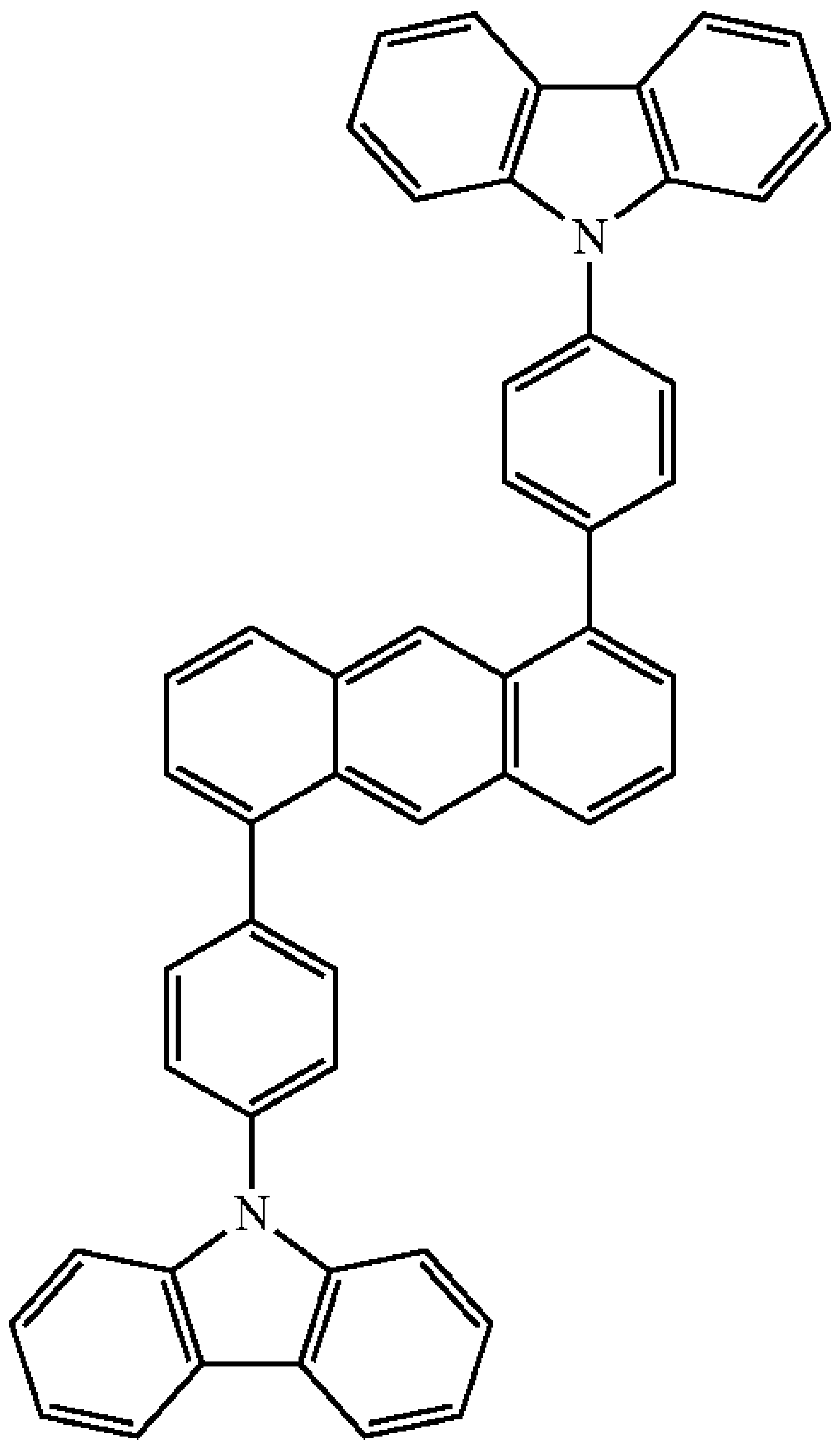
Thus, in the above structure, an energy difference between any one of the T_n levels of the first organic compound and any one of the S_1 level and the S_n levels of the first organic compound is 1 eV or less.

In each of the above structures, an oscillator strength for excitation from the T_1 level of the first organic compound to one of the levels of the triplet excited states higher than the T_1 level of the first organic compound is 0.0015 or more.

In each of the above structures, the first organic compound is an organic compound (host material) in which TTA can be efficiently caused and triplet excitons, which do not contribute to light emission, are converted into singlet excitons. Thus, the first organic compound preferably includes a tetracene skeleton or an anthracene skeleton.

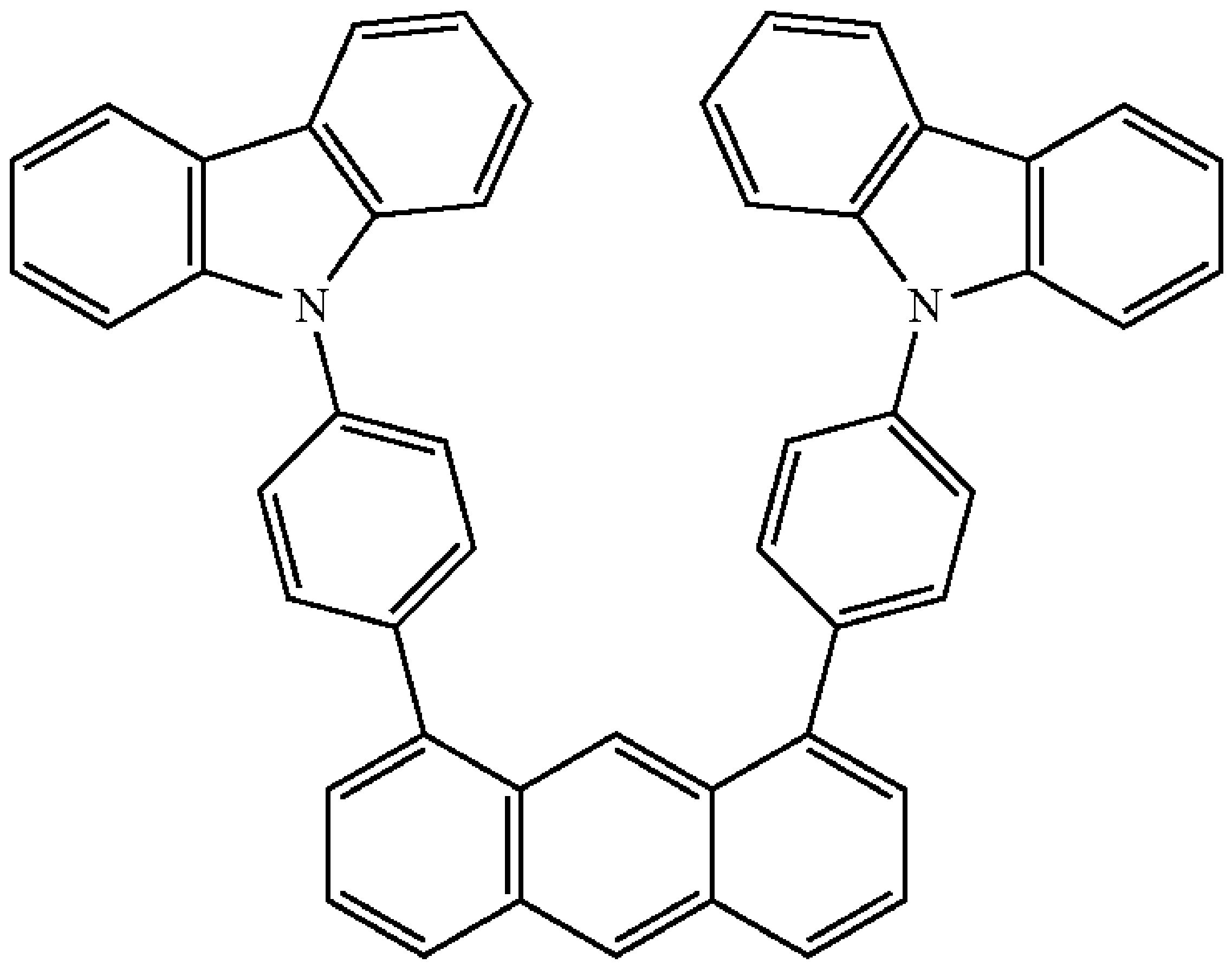
In each of the above structures, the first organic compound has Structural Formula (100) or Structural Formula (110).

(100)



1,5CzP2A

(110)



1,8CzP2A

The above-described first organic compound is an organic compound (host material) in which TTA can be efficiently caused, triplet excitons, which does not contribute to light emission, can be efficiently converted into singlet excitons, and the proportion of delayed fluorescence to the total light emitted from the organic compound is high because the triplet exciton has long excitation lifetime.

Thus, in the light-emitting element which includes the first organic compound in the light-emitting layer and which has the above structure, the light-emitting element exhibits delayed fluorescence, and emission intensity of the delayed fluorescence component to the emission intensity of the total light emitted from the light-emitting element is at least 5% or more, preferably 10% or more, further preferably 15% or more for obtaining higher efficiency. Note that in the case where the energy of triplet excitons is converted into the energy of singlet excitons through TTA, the proportion of delayed fluorescence due to TTA to the total light emitted from the light-emitting element can be increased because the proportion of singlet excitons having a light-emitting property is increased. Note that in the case where a second organic compound that is a guest material is included in the light-emitting layer, because light emission may occur due to direct recombination of carriers in the guest material without the host material, the proportion of delayed fluorescence to the total light emission may be decreased compared to the case of an element structure which is the same as that of the light-emitting element except for not including the guest material.

In the above structures, the light-emitting layer comprises the first organic compound and the second organic compound, and an S_1 level of the first organic compound is higher than an S_1 level of the second organic compound. Moreover, light emission from the light-emitting element is derived from the second organic compound.

In the above structure, the second organic compound includes a pyrene skeleton.

In each of the above structures, a T_1 level of the second organic compound is higher than the T_1 level of the first organic compound.

In each of the above structures, the EL layer includes a hole-transport layer and a light-emitting layer. The hole-transport layer in contact with the light-emitting layer is located between the anode and the light-emitting layer. The hole-transport layer comprises a third organic compound, and a T_1 level of the third organic compound is higher than the T_1 level of the first organic compound.

In each of the above structures, the EL layer includes an electron-transport layer and a light-emitting layer. The electron-transport layer in contact with the light-emitting layer is located between the cathode and the light-emitting layer. The electron-transport layer comprises a fourth organic compound and a T_1 level of the fourth organic compound is higher than the T_1 level of the first organic compound.

Another embodiment of the present invention is a light-emitting device including the light-emitting element having any one of the above structures and one of a transistor and a substrate.

Another embodiment of the present invention is an electronic device including the light-emitting device having any one of the above structures and any one of a microphone, a camera, an operation button, an external connection portion, and a speaker.

Another embodiment of the present invention is an electronic device including the light-emitting device having the above-described structure and one of a housing and a touch sensor function.

Another embodiment of the present invention is a lighting device including the light-emitting device having the above-described structure, and any one of a housing, a cover, and a support.

The present invention includes, in its scope, not only a light-emitting device including the light-emitting element but also a lighting device including the light-emitting device. The light-emitting device in this specification refers to an image display device and a light source (e.g., a lighting device). In addition, the light-emitting device includes, in its category, all of a module in which a connector such as a flexible printed circuit (FPC) or a tape carrier package (TCP) is connected to a light-emitting device, a module in which a printed wiring board is provided on the tip of a TCP, and a module in which an integrated circuit (IC) is directly mounted on a light-emitting element by a chip on glass (COG) method.

A lighting system that is another embodiment of the present invention has a structure in which driving of a light-emitting element that is a light source is controlled in accordance with external information obtained from a sensor. Note that as the light-emitting element in the lighting system, the above-described light-emitting element which is one embodiment of the present invention is preferably used.

That is, one embodiment of the present invention is a lighting system including a sensor, a control unit, and a light-emitting element. Information detected by the sensor is input to the control unit. The control unit is configured to drive the light-emitting element electrically connected to the control unit on the basis of the information. The light-emitting element includes an EL layer between an anode and a cathode. The EL layer includes a light-emitting layer. The light-emitting layer includes a first organic compound. A difference between a T_1 level of the first organic compound and one or more of T_n levels of the first organic compound is less than the sum of the T_1 level and 0.6 eV.

Another embodiment of the present invention is a lighting system including a sensor, a control unit, and a light-emitting element. The control unit includes a communication unit, a CPU, and a memory. The memory includes a program for driving the light-emitting element based on exterior information. The communication unit is configured to send the exterior information acquired by the sensor to the CPU. The CPU is configured to drive the light-emitting element by reading out the program from the memory and executing the program. The light-emitting element includes an EL layer between an anode and a cathode. The EL layer includes a light-emitting layer. The light-emitting layer includes a first organic compound. A difference between a T_1 level of the first organic compound and one or more of T_n levels of the first organic compound is less than the sum of the T_1 level and 0.6 eV.

According to one embodiment of the present invention, a light-emitting element containing a fluorescent compound, which has high efficiency can be provided. According to one embodiment of the present invention, a light-emitting element in which the proportion of delayed fluorescence to the total light emitted from the light-emitting element is higher than that in a conventional light-emitting element can be provided. According to one embodiment of the present invention, a novel light-emitting element and a novel light-emitting device can be provided. A novel light-emitting device, a novel electronic device, or a novel lighting device can be provided. A lighting system in which energy saving of a light-emitting element that is a light source is achieved can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIGS. **1**A to **1**D each illustrate a mechanism of TTA;

FIG. **2** shows the directions of transition dipole moments and oscillator strengths in molecular structures;

FIG. **3** shows the directions of the transition dipole moments and oscillator strengths in molecular structures;

FIGS. **4**A and **4**B each illustrate a structure of a light-emitting element;

FIGS. **5**A and **5**B each illustrate a structure of a light-emitting element;

FIGS. **6**A to **6**C illustrate a light-emitting device;

FIGS. **7**A and **7**B illustrate a light-emitting device;

FIGS. **8**A, **8**B, **8**C, **8**D, **8**D'-**1** and **8**D'-**2** illustrate electronic devices;

FIGS. **9**A to **9**C illustrate an electronic device;

FIGS. **10**A and **10**B illustrate an automobile;

FIGS. **11**A to **11**D illustrate lighting devices;

FIG. **12** illustrates lighting devices;

FIGS. **13**A and **13**B illustrate an example of a touch panel;

FIGS. **14**A and **14**B illustrate an example of a touch panel;

FIGS. **15**A and **15**B illustrate an example of a touch panel;

FIGS. **16**A and **16**B are a block diagram and a timing chart of a touch sensor;

FIG. **17** is a circuit diagram of a touch sensor;

FIG. **18** illustrates a light-emitting element;

FIG. **19** shows attenuation curves;

FIG. **20** is a graph showing the current density vs. luminance characteristics of Light-emitting element **1** and Light-emitting element **3**;

FIG. **21** is a graph showing the voltage vs. luminance characteristics of Light-emitting element **1** and Light-emitting element **3**;

FIG. **22** is a graph showing the luminance vs. current efficiency characteristics of Light-emitting element **1** and Light-emitting element **3**;

FIG. **23** is a graph showing voltage-current characteristics of Light-emitting element **1** and Light-emitting element **3**;

FIG. **24** is a graph the current density vs. luminance characteristics of Light-emitting element **2** and Light-emitting element **4**;

FIG. **25** is a graph showing the voltage vs. luminance characteristics of Light-emitting element **2** and the Light-emitting element **4**;

FIG. **26** is a graph showing the luminance vs. current efficiency characteristics of Light-emitting element **2** and Light-emitting element **4**;

FIG. **27** is a graph showing voltage-current characteristics of Light-emitting element **2** and Light-emitting element **4**;

FIG. **28** shows emission spectra of Light-emitting element **1** and Light-emitting element **3**;

FIG. **29** shows emission spectra of Light-emitting element **2** and Light-emitting element **4**;

FIGS. **30**A and **30**B are ^{1}H NMR charts of an organic compound represented by Structural Formula (100);

FIGS. **31**A and **31**B shows an ultraviolet-visible absorption spectrum and an emission spectrum of the organic compound represented by Structural Formula (100);

FIG. **32** shows results of LC/MS analysis of the organic compound represented by Structural Formula (100);

FIGS. **33**A and **33**B are ^{1}H NMR charts of an organic compound represented by Structural Formula (110);

FIGS. **34**A and **34**B show ultraviolet-visible absorption spectra and emission spectra of the organic compound represented by Structural Formula (110);

FIG. **35** shows results of LC/MS analysis of the organic compound represented by Structural Formula (110);

FIGS. **36**A, **36**B**1**, and **36**B**2** show block diagrams of a display device;

FIG. **37** shows a circuit structure of a display device;

FIG. **38** is a cross-sectional structure of a display device;

FIGS. **39**A and **39**B illustrate a light-emitting element; and

FIG. **40** illustrates a structure of a lighting system.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings. Note that the present invention is not limited to the following description, and modes and details thereof can be variously changed without departing from the spirit and scope of the present invention. Therefore, the present invention should not be construed as being limited to the description in the following embodiments.

Note that the terms "film" and "layer" can be interchanged with each other according to circumstances. For example, in some cases, the term "conductive film" can be used instead of the term "conductive layer," and the term "insulating layer" can be used instead of the term "insulating film".

Embodiment 1

In this embodiment, a mechanism of occurrence of TTA (triplet-triplet annihilation) in an EL layer of a light-emitting element is described.

There are various theories on the detail of the mechanism of TTA, and it is not defined clearly. In one embodiment of the present invention, energy transfer shown in schemes in FIGS. **1**A to **1**D is assumed to occur in TTA.

First, in the case where triplet excitons of two molecules of the same kind (a molecule A and a molecule B) exist adjacently as shown in FIG. **1**A, energy released when the molecule B transits from a T_1 level to an S_0 level is absorbed by the molecule A, and an electron at the T_1 level of the molecule A transits to a T_n level. Thus, it is thought that the vicinity of an energy level that is higher than the T_1 level of the molecule A by the T_1 level of the molecule B is the T_n level to which the molecule A can transit.

Next, as shown in FIG. **1**B, the electron transited to the T_n level of the molecule A undergoes intersystem crossing into an S_n level whose energy level is close to the T_n level with a certain probability. Furthermore, the electron at the S_n level transits to a S_1 level by internal transition (FIG. **1**C).

When the electron at the S_1 level transits to the S_0 level as shown in FIG. **1**D, delayed fluorescence is generated.

As described above, using the excitation energy of one of two molecules, the other molecule transits to a higher level; thus, up to half of 75% of T_1 excitons can be extracted as emission. Since there is also 25% of S_1 excitons generated by current excitation, the total internal quantum efficiency can be 62.5% at the maximum.

Note that in the case where intermolecular energy transfer through TTA described in FIGS. **1**A to **1**D occurs, an increase in the efficiency of energy transfer from the molecule B to the molecule A in FIG. **1**A increase the probability of transition from the T_1 level to the T_n level, thereby increasing the number of S_1 excitons that are finally generated. As mechanisms of such intermolecular energy transfer, two mechanisms, i.e., the Dexter mechanism (electron exchange interaction) and the Förster mechanism (dipole-dipole interaction) are given. The fact that the energy transfer between triplet excitons (T_1-T_1) is possible in either of the mechanisms is described below.

In the Dexter mechanism, electron spins of both two molecules are stored before and after energy transfer. Thus, when the electron spins of both two molecules are stored before and after energy transfer, energy transfer by the Dexter mechanism is allowed. Note that energy transfer through TTA has been mainly described using the Dexter mechanism.

Meanwhile, the rate constant k_{ET} of energy transfer in the Förster mechanism is expressed by Formula (1) below.

$$k_{ET} = \frac{9000c^4\ln 10}{128\pi^5 n^4 N_A \tau_0^a}\frac{\kappa^2}{R^6}\int f_a(\tilde{v})\varepsilon_b(v)\frac{d\tilde{v}}{\tilde{v}^4} \tag{1}$$

c: The velocity of light, n: refractive index, N_A: Avogadro number, τ_0: donor duration, R: intermolecular distance, K^2: relative orientation factor of transition dipole moments of A and B, $\tilde{v}$: wave number, f: light intensity per wave number standardized to Area 1, ε: absorption coefficient

Note that τ_0 in Formula (1) is the reciprocal number of radiation speed k_r. Here, x is expressed as follows.

$$x = \frac{9000c^4 \ln 10}{128\pi^5 n^4 N_A} \frac{\kappa^2}{R^6} \int f_a(\tilde{\nu}) \varepsilon_b(\nu) \frac{d\tilde{\nu}}{\tilde{\nu}^4}$$

Formula (1) can be represented by Formula (1') using x.

$$k_{ET} = xk_r \tag{1'}$$

Furthermore, energy transfer efficiency ϕ_{ET} by the Förster mechanism is represented by Formula (2) below.

$$\phi_{ET} = \frac{k_{ET}}{k_r + k_{nr} + k_{ET}} \tag{2}$$

k_r: radiative rate constant, k_{nr}: non-radiative rate constant

Formula (2') can be derived from Formula (2) and Formula (1') as follows.

$$\begin{aligned} \phi_{ET} &= \frac{xk_r}{k_r + k_{nr} + xk_r} \\ &= \frac{x}{\left(\frac{k_r + k_{nr}}{k_r}\right) + x} \\ &= \frac{x}{\left(\frac{1}{\phi_p}\right) + x} \end{aligned} \tag{2'}$$

ϕ_p: phosphorescence quantum efficiency

In the case where the molecule A and the molecule B are anthracene derivatives, a radiation rate constant (k_r) of phosphorescent emission obtained from the anthracene derivatives is 1×10^3 (s^{-1}) to 1×10^4 (s^{-1}) and a non-radiation rate constant (k_{nr}) thereof is 1×10^7 (s^{-1}) to 1×10^8 (s^{-1}). Accordingly, the phosphorescence quantum efficiency (ϕ_p) can be estimated to be 1×10^{-3} to 1×10^{-5}.

Here, when the phosphorescence quantum efficiency (ϕ_p) is 1×10^{-4} and x is 100, the energy transfer efficiency (ϕ_{ET}) is 1.0%. If x is 1000, the energy transfer efficiency (ϕ_{ET}) is 9.1%. Note that there is a positive correlation between x and an absorption coefficient; thus, as the absorption coefficient is increased, x is also increased. That is, even in the case where the phosphorescence quantum efficiency (ϕ_p) of the molecule on a donor side (the molecule B in FIGS. **1**A to **1**D) is low, if the absorption coefficient of the molecule on an acceptor side (the molecule A in FIGS. **1**A to **1**D) is high, the energy transfer by the Förster mechanism can occur.

As described above, energy transfer between triplet excitons can partly occur by the Förster mechanism. Thus, here, the energy transfer through TTA by not only the Dexter mechanism but also that by the Förster mechanism are considered.

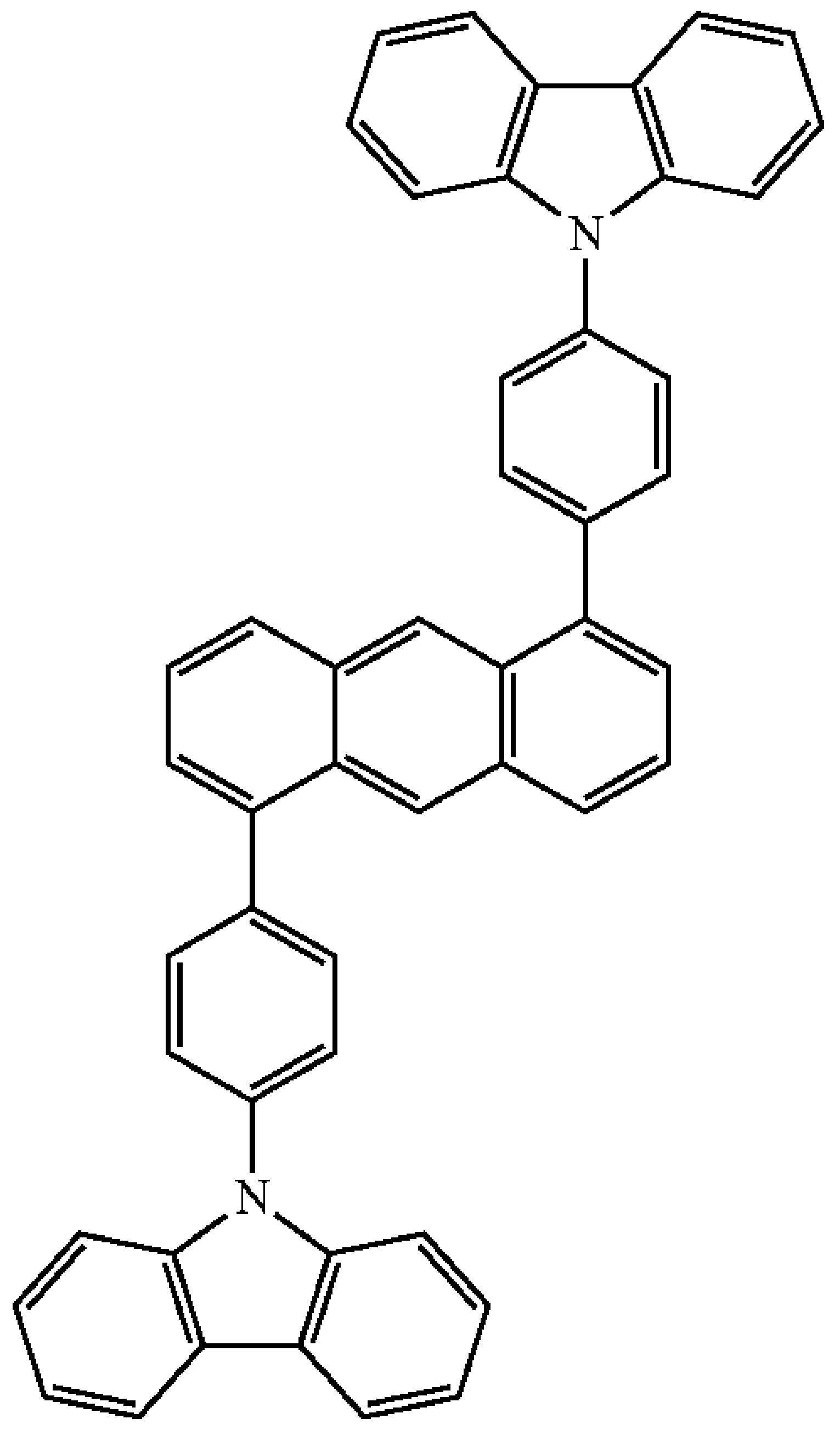
In the case where the energy transfer by the Förster mechanism is caused, as shown in the following Formula (3), generally, the absorption coefficient of the molecule is high when the oscillator strength (f) of the molecule is large.

$$f = 4.32\times10^{-9} \int \varepsilon(\tilde{\nu}) d\tilde{\nu} \tag{3}$$

f: oscillator strength, ε: absorption coefficient

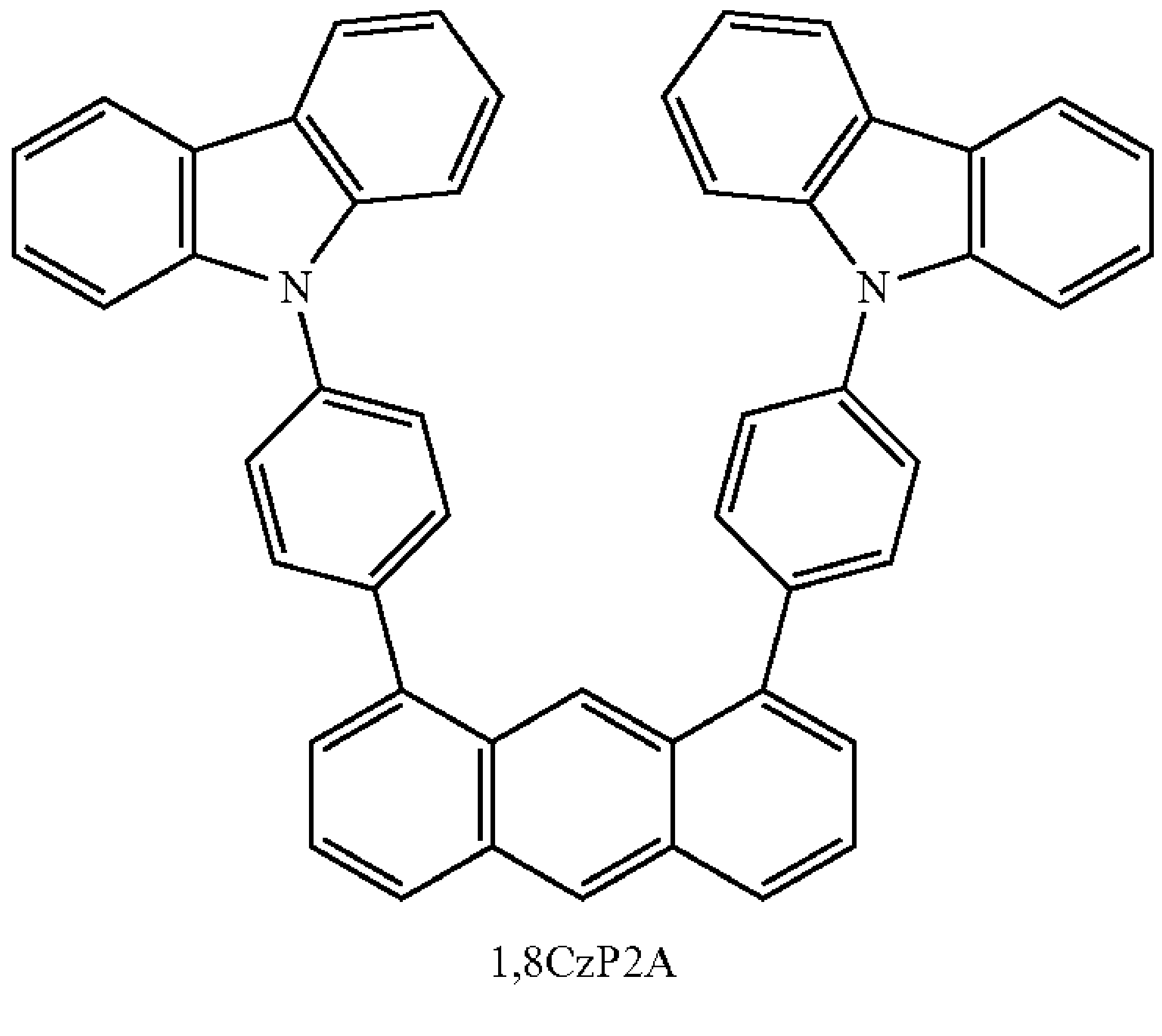
Hence, a molecular design is performed using quantum chemical calculations so that the oscillator strength (f) between the triplet excited state (T_1) that is the lowest level and the triplet excited state (T_n) that is higher than the T_1 is increased. However, in the case where there is a plurality of triplet excited states (T_n) that is higher than T_1, the total of the oscillator strengths in the triplet excited states is considered to be the oscillator strength (f). Note that by the molecular design, it is found that the oscillator strength (f) of the molecule is increased when a compound including an anthracene skeleton is used. Structural formulae of the compounds each including an anthracene skeleton are shown below.

(100)



1,5CzP2A

(110)



1,8CzP2A

The quantum chemical calculation method of the above compound is as follows. Note that Gaussian 09 is used as the quantum chemistry computational program. A high performance computer (ICE X manufactured by SGI Japan, Ltd.) is used for the calculation.

First, stable structures and electron states in the singlet ground state (S_0) and the T_1 state are calculated using the density functional theory (DFT). After that, vibration analysis is conducted, and the T_1 level is calculated from the energy difference between the stable structures in the S_0 state and in the T_1 state. As a basis function, 6-311G (d,p) is used. As a functional, B3LYP is used. In the DFT, the total energy of the molecules is represented as the sum of potential energy, electrostatic energy between electrons, electronic kinetic energy, and exchange-correlation energy including all the complicated interactions between electrons. Also in the DFT, an exchange-correlation interaction is approximated by a functional (a function of another function) of one electron potential represented in terms of electron density; thus, electron states can be obtained with high accuracy.

Next, a time-dependent density functional theory (TD-DFT) is used to calculate the transition dipole moment and the oscillator strength (f) which relate to the transition from the T_1 level to the T_n level. As a basis function, 6-311G(d,p) is used, and as a functional, CAM-B3LYP is used. In the calculation using TD-DFT, stable structures and electron states in the T_1 state obtained from the calculation using CAM-B3LYP as a functional of DFT are used.

Note that a T_n state in TD-DFT indicates a triplet excited state at an energy level lower than a value obtained by adding 0.6 eV to excitation energy corresponding to twice the T_1 level by the calculation using TD-DFT. However, even if an excited state satisfying the above condition is included in a portion other than an anthracene skeleton in the compound including the anthracene skeleton, it is excluded from the T_n state because of being not involved in triplet excitation of the entire compound.

From the calculation using TD-DFT, the T_1 level of 1,5CzP2A is 1.67 eV and the T_1 level of 1,8CzP2A is 1.66 eV. From the calculation using TD-DFT, it is found that there are two triplet excited states corresponding to the T_n levels where excitation energy from the T_1 level is less than a value obtained by adding 0.6 eV to the T_1 level in each of 1,5CzP2A and 1,8CzP2A. Note that excitation energies from the T_1 level to the T_n level in 1,5CzP2A are 1.80 eV and 2.07 eV, and excitation energies from the T_1 level to the T_n level in 1.8CzP2A was 1.81 eV and 2.06 eV.

FIG. **2** shows the directions of the transition dipole moment between the T_1 level to the T_n level and the oscillator strengths (f) of each of 1,5CzP2A and 1,8CzP2A, obtained from the calculation using TD-DFT. Note that in the molecular arrangement of the molecules in FIG. **2**, the major axis of the anthracene skeleton is aligned with the x-axis and the minor axis is aligned with the y-axis.

As shown in FIG. **2**, the transition dipole moment of 1,8CzP2A is formed mainly using components in the X-axis direction (an arrow "a" in FIG. **2**); the transition dipole moment of 1,5CzP2A is formed using components in the X-axis direction and Y-axis direction (an arrow "b" in FIG. **2**). Note that the oscillator strength (f) of 1,8CzP2A is calculated to be 0.0020, and the oscillator strength (f) of 1,5CzP2A is calculated to be 0.0032. The results reveals that the oscillator strength (f) of 1,5CzP2A is larger than that of 1,8CzP2A, and the transition between the T_1 level and the T_n level more easily occurs in 1,5CzP2A than in 1,8CzP2A. That is, 1,5CzP2A has a higher probability of TTA caused by energy transfer by the Förster mechanism than 1,8CzP2A.

The magnitude of the transition dipole moment and the oscillator strength (f) have a relation shown in Formulae (4) in which the oscillator strength (f) is proportional to the square of the magnitude of the transition dipole moment.

$$f = \frac{|\mu_{mn}|^2}{|\mu_0|^2} \tag{4}$$

$$|\mu_0|^2 = \frac{3he^2}{8\pi mv}$$

f: oscillator strength, μ_{mn}: transition dipole moment, μ_0: oscillation electric dipole moment, h: Planck constant, e: quantum of electricity, m: mass of electrons, v: wave number

In each of 1,5CzP2A and 1,8CzP2A, the compound is divided into an anthracene skeleton **501** and carbazole skeletons **502** as units (skeletons) constituting the compound, and the transition dipole moment in the transition from the T_1 level to the T_n level in each of the units is analyzed. Here, only the transition between the main molecular orbits of the transition with the largest oscillator strength among the transitions from the T_1 level to the T_n level, is analyzed. FIG. **3** shows the results.

From the results in FIG. **3**, in 1,8CzP2A, the components of the two carbazole skeletons **502** in the y-axis direction of the transition dipole moment are in the direction opposite to each other, thereby weakening the components in the y-axis direction for each other. In 1,5CzP2A, the components of the two carbazole skeletons **502** in the y-axis direction of the transition dipole moment are in the same direction, thereby strengthening the components the y-axis direction for each other. As a result, in the entire 1,5CzP2A, the magnitude of the transition dipole moment in the y-axis direction derived from the carbazole skeletons **502** is large. Thus, as shown in the above Formulae (4), it is found that the oscillator strength (f) of 1,5CzP2A having a larger transition dipole moment is larger than that of 1,8CzP2A. That is, the following can be said, also in view of the molecular structure, that the oscillator strength (f) of 1,5CzP2A is larger than that of 1,8CzP2A, the transition between the T_1 level and the T_n level more easily occurs in 1,5CzP2A than in 1,8CzP2A, and thus 1,5CzP2A has a higher probability of TTA caused by energy transfer by the Förster mechanism than 1,8CzP2A.

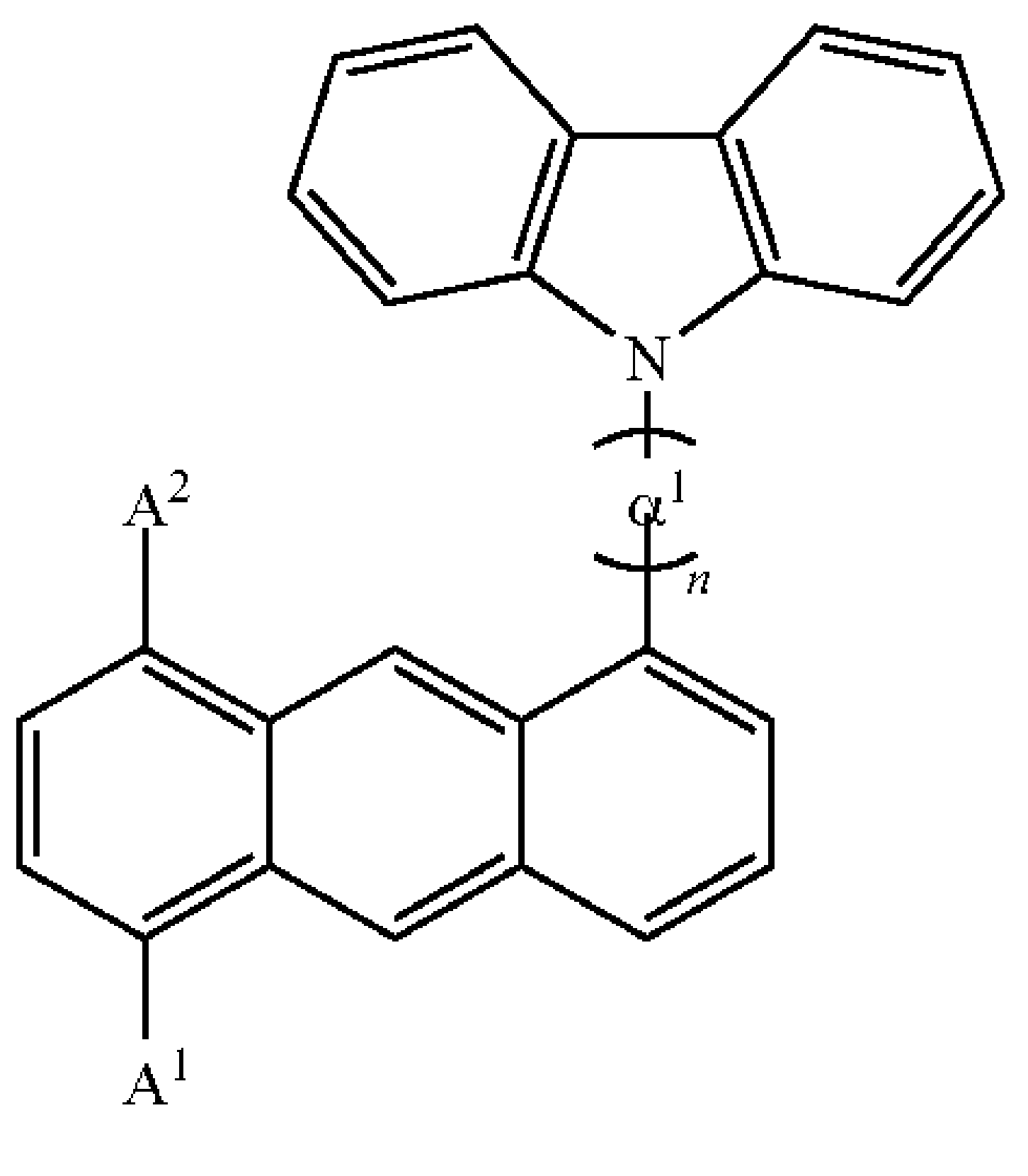
Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 2

In this embodiment, an organic compound of one embodiment of the present invention will be described. The organic compound described in this embodiment is an organic compound in which the probability of TTA caused by energy transfer by the Förster mechanism can be increased, as in 1,5CzP2A and 1,8CzP2A described as examples in Embodiment 1.

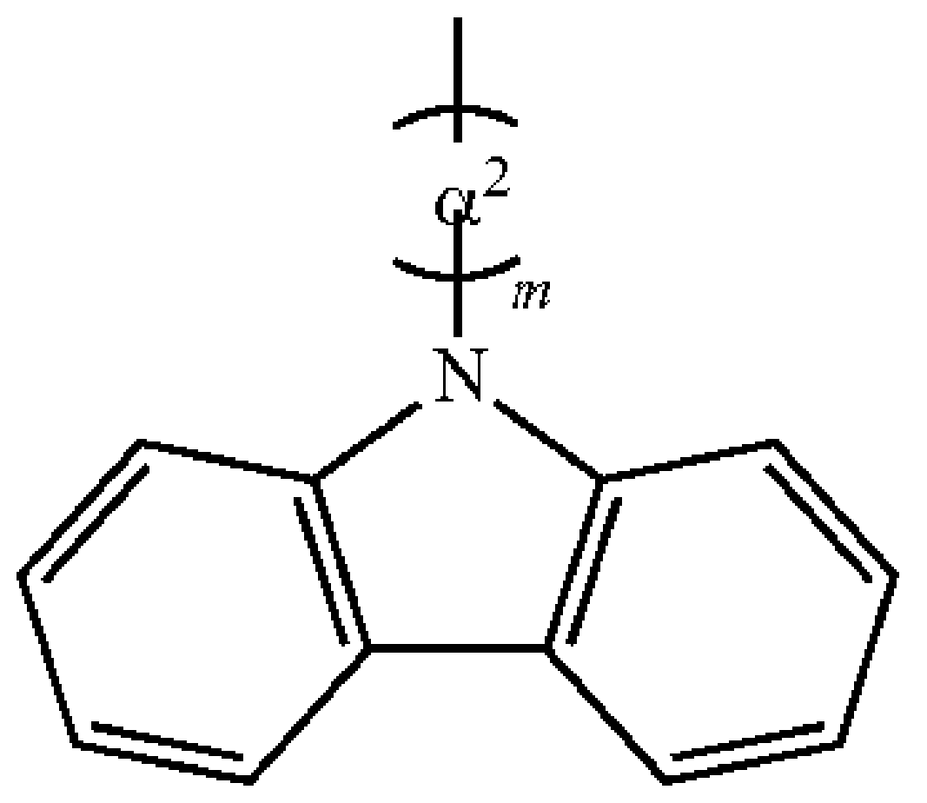
The organic compound described in this embodiment has a feature in that a carbazole skeleton is bonded to an anthracene skeleton directly or through an arylene group. The organic compound described in this embodiment is an organic compound having a structure represented by General Formula (G1).

(G1)



-continued

(G1-1)



Note that either of A^1 and A^2 in General Formula (G1) is a substituent represented by General Formula (G1-1), and the other is hydrogen or another substituent. That is, α^2 is bonded to the 5-position or 8-position of the anthracene skeleton in General Formula (G1). In addition, α^1 and α^2 individually represent a substituted or unsubstituted phenylene group. Furthermore, n and m individually represent 1 or 2. Furthermore, General Formula (G1) may include one or more substituents. When General Formula (G1) includes the one or more substituents and either of A^1 and A^2 is the another substituent, they independently represent an alkyl group having 1 to 6 carbon atoms, a cycloalkyl group having 1 to 6 carbon atoms, an alkylphenyl group, or a phenyl group.

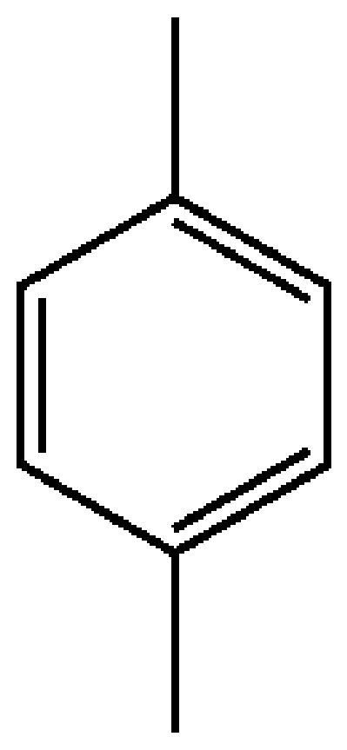
Note that as the substitution site of General Formula (G1-1), A^1 is preferred to A^2 in General Formula (G1) because the total of the oscillator strengths for excitation from the T_1 level to the T_n level tends to be larger.

Furthermore, as the substitution site of General Formula (G1-1), A^1 is preferred to A^2 because the two substituents each including the carbazole skeleton are bonded to a 1-position and a 5-position of the anthracene skeleton, and steric repulsion of the two substituents each including the carbazole skeleton is prevented. Similarly, when General Formula (G1) has other substituents, it is preferable that the substituents be provided so as not to be adjacent (e.g., at the 1- and 2-positions, the 2- and 3-positions, and the 1- and 9-positions) to each other at the same time because the steric repulsion can be prevented.

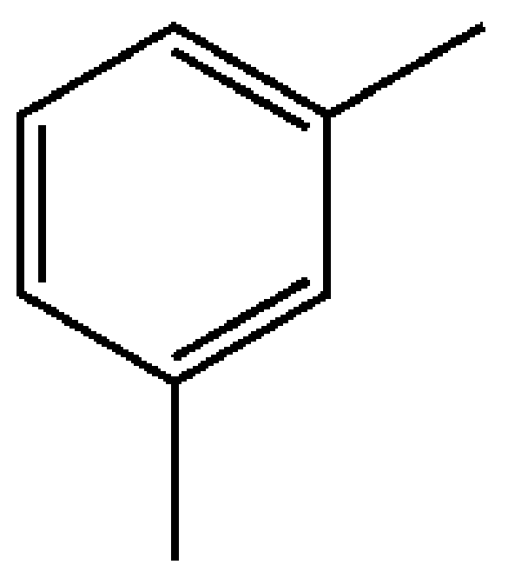
Note that in General Formulae (G1) and (G1-1), examples of phenylene groups represented by α^1 and α^2 include a para-phenylene group, a meta-phenylene group, and an orthophenylene group.

Specific examples of the phenylene groups represented by α^1 and α^2 in General Formulae (G1) and (G1-1) are represented by Structural Formulae (α-1) to (α-5).

(α-1)



(α-2)



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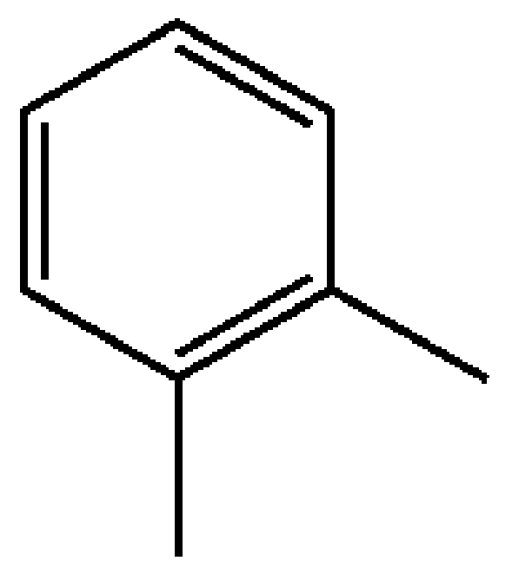
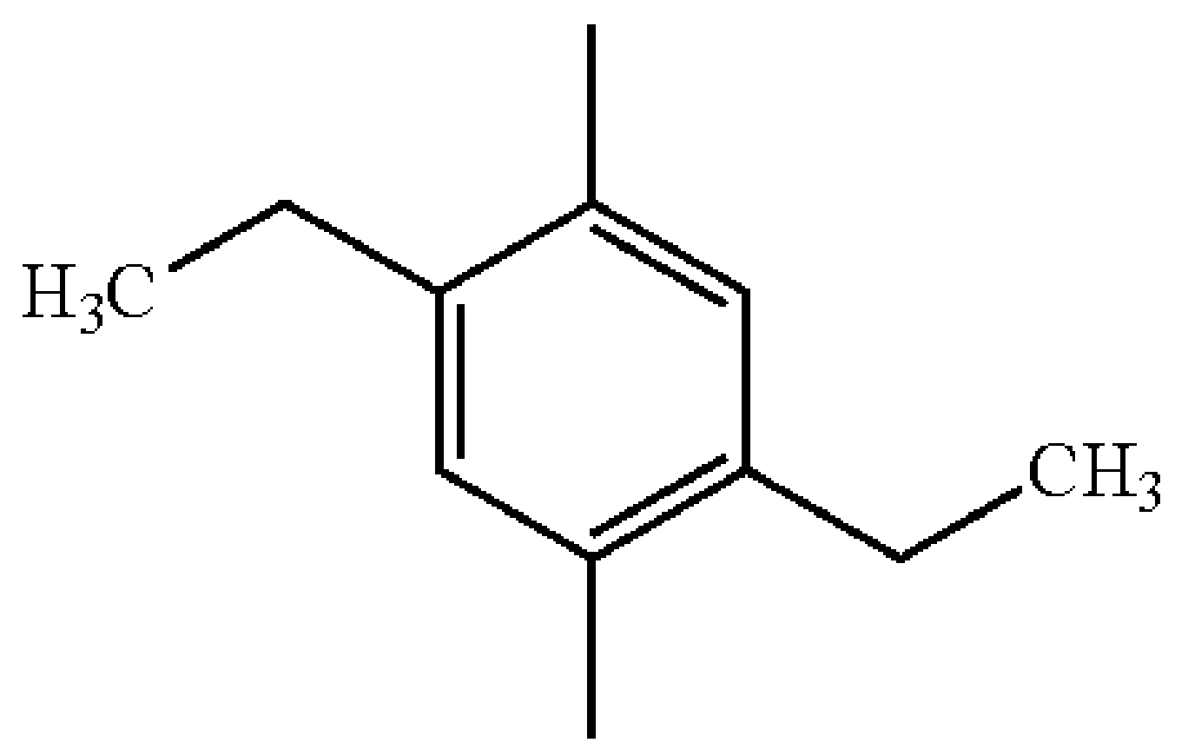
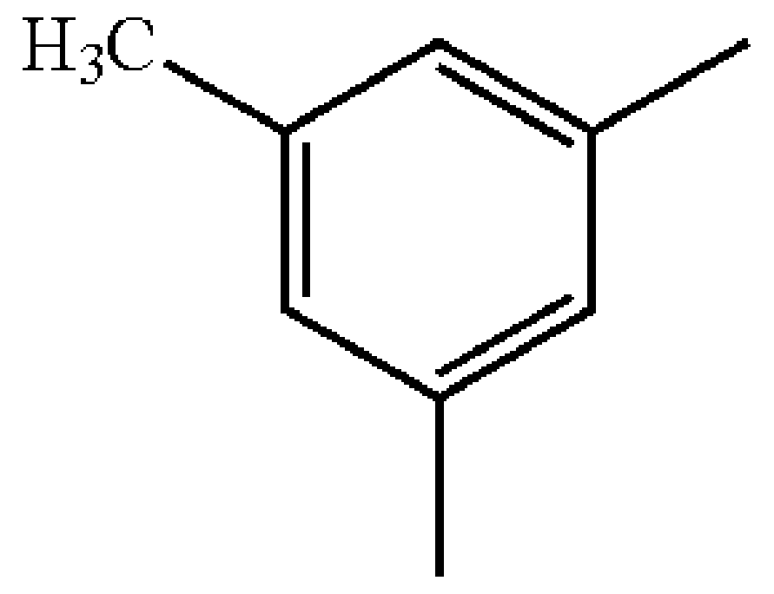
(α-3)



(α-4)



(α-5)

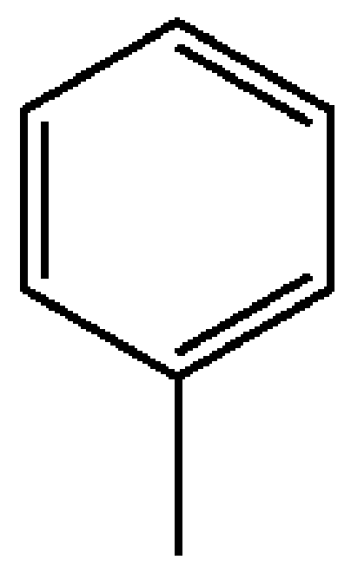


In the phenylene groups represented by α^1 and α^2 in General Formulae (G1) and (G1-1), the substitution sites of the carbazole skeleton and the anthracene skeleton can be any positions of a para-position, a meta-position, and an ortho-position. When the phenylene group has the substituents at the para-position, a high carrier-transport property is obtained, which is preferable. When the phenylene group has the substituents at the meta-position, a bulky structure is obtained and thus evaporation temperature can be low, which is preferable.

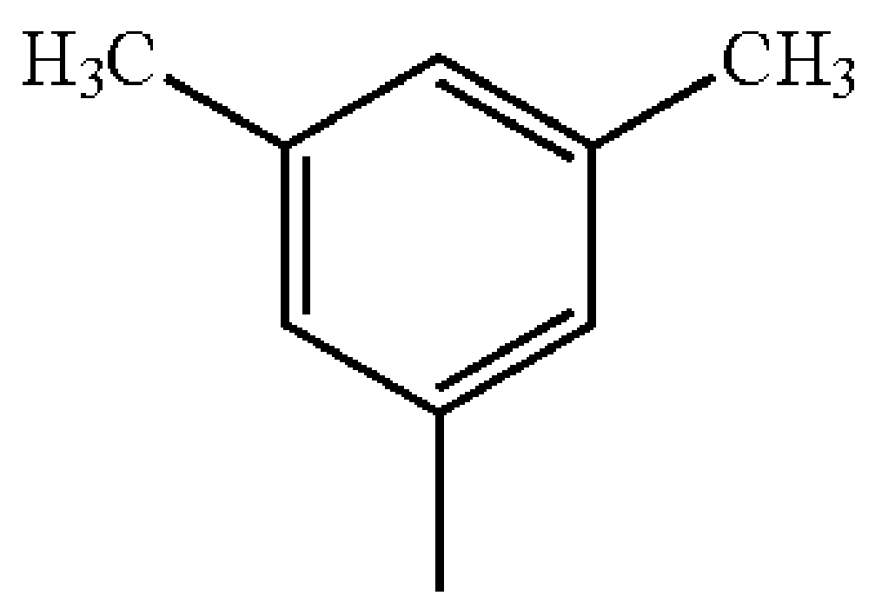
In the case where the phenylene groups represented by α^1 and α^2 in General Formulae (G1) and (G1-1) further have substituents, examples of the substituents include an alkyl group having 1 to 6 carbon atoms and a cycloalkyl group having 1 to 6 carbon atoms. Specific examples include a methyl group, an ethyl group, a propyl group, an isopropyl group, a butyl group, a tert-butyl group, a pentyl group, an isopentyl group, a hexyl group, an isohexyl group, and a cyclohexyl group.

Furthermore, specific examples of the substituents of the phenylene groups represented by α^1 and α^2 in General Formulae (G1) and (G1-1) are represented by Structural Formulae (R-1) to (R-11).

(R-1)



(R-2)



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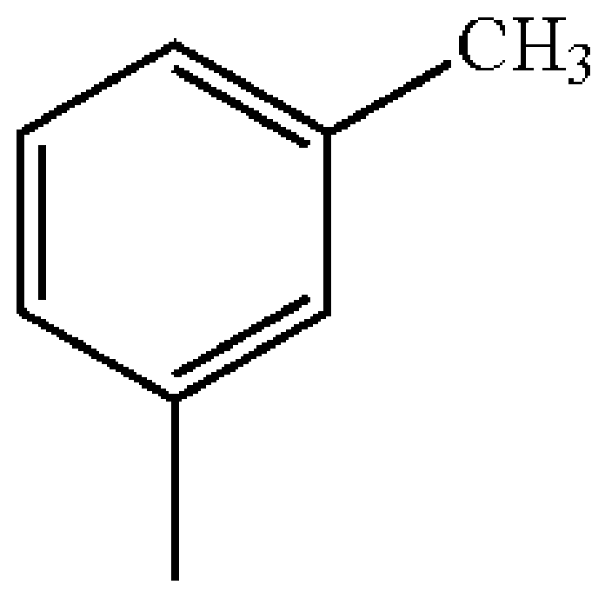
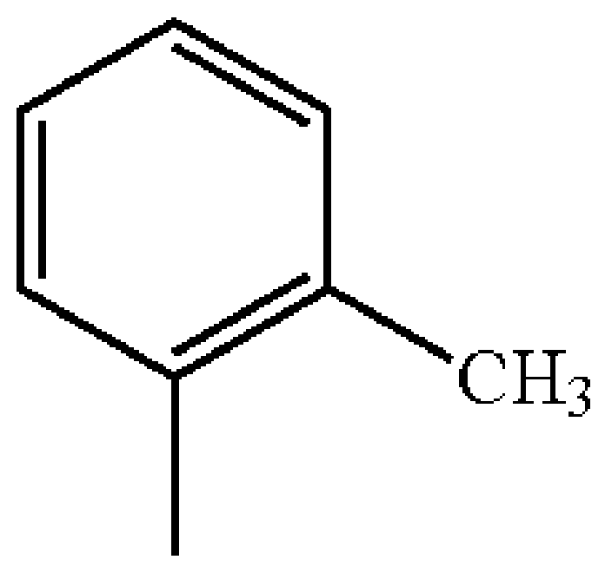
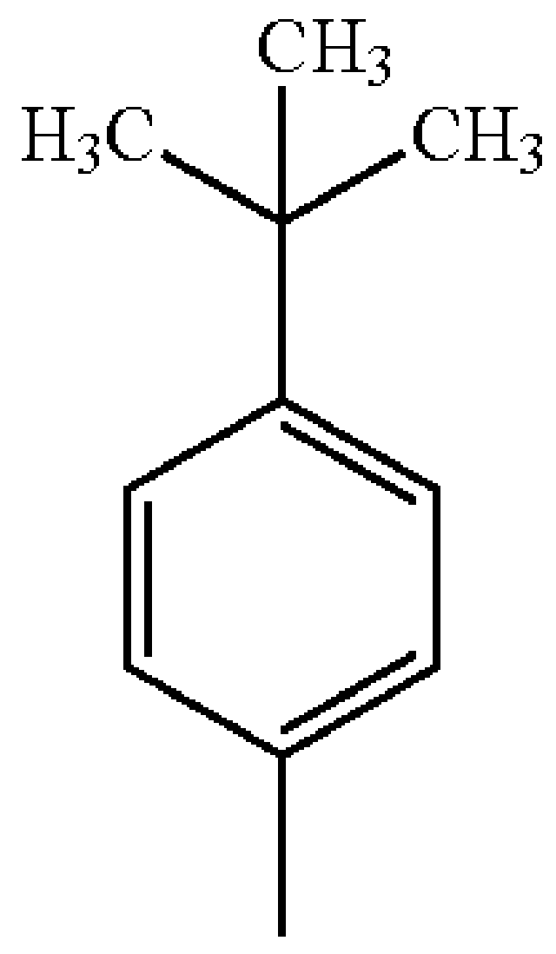
(R-3)



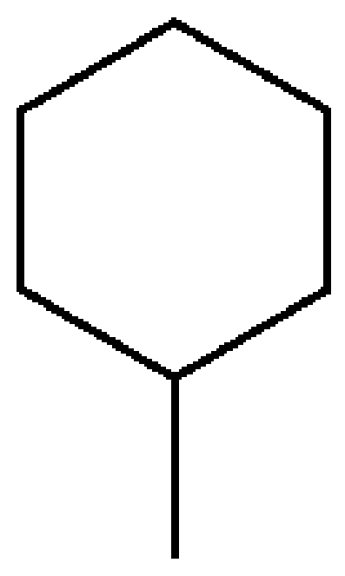
(R-4)



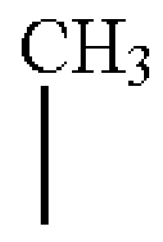
(R-5)



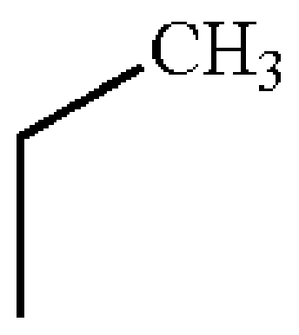
(R-6)



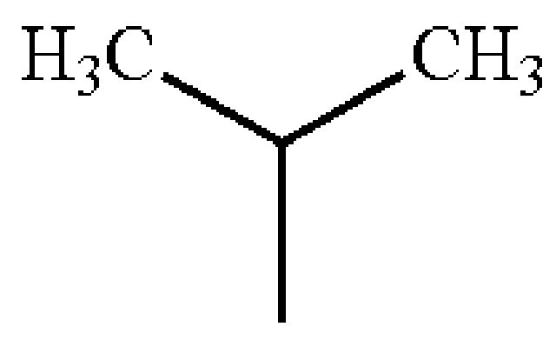
(R-7)



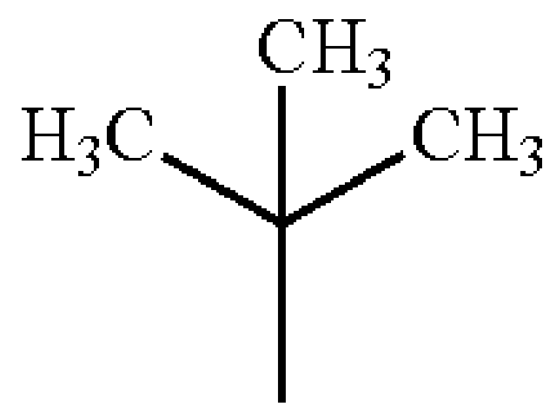
(R-8)



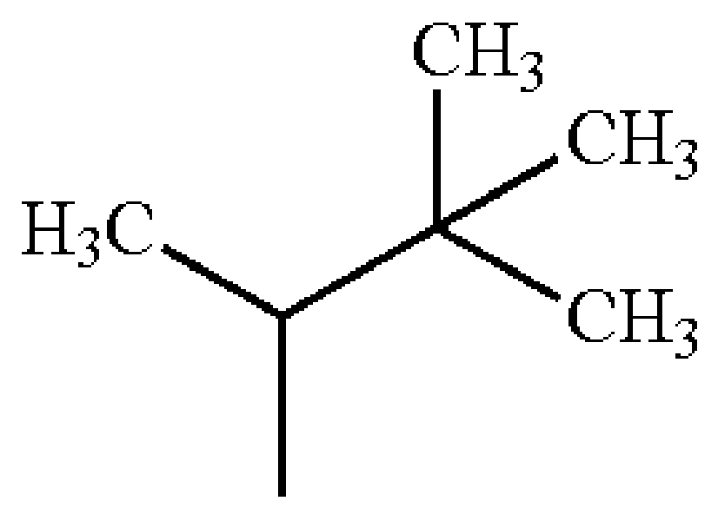
(R-9)



(R-10)



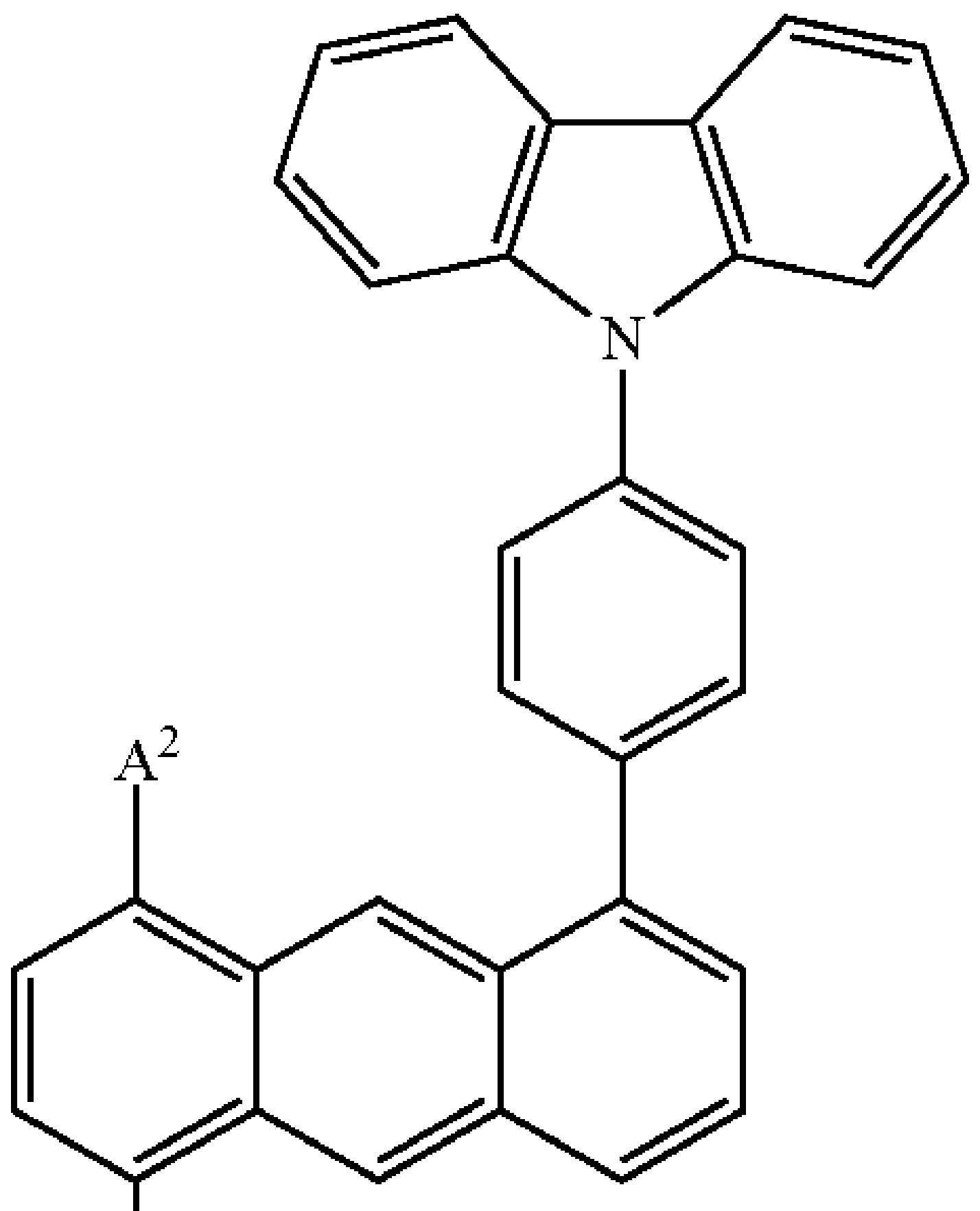
(R-11)



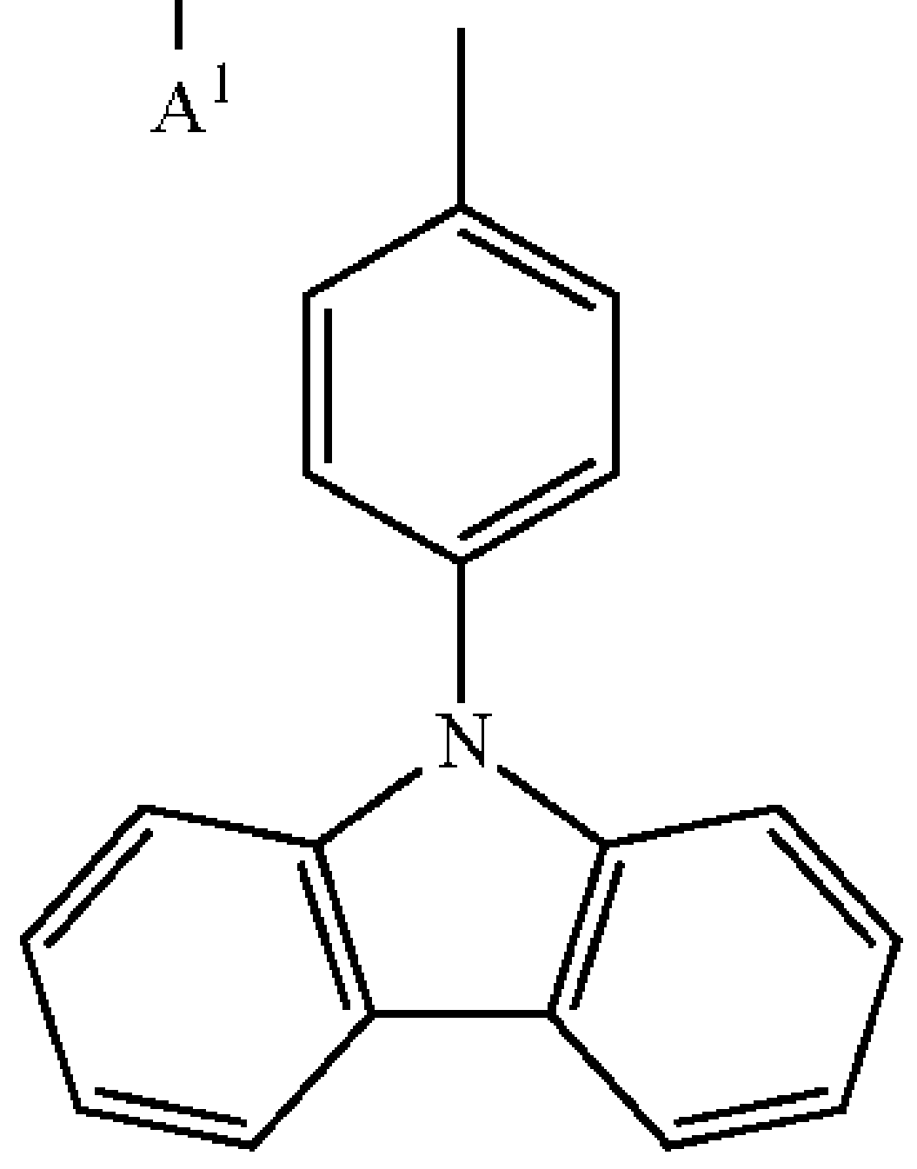
In the case where the phenylene groups represented by α^1 and α^2 in General Formulae (G1) and (G1-1) have the substituents, improvement in solubility and improvement in thermophysical property can be expected, which is preferable. Meanwhile, in the case where the phenylene groups represented by α^1 and α^2 in the General Formulae (G1) and (G1-1) do not have the substituents, synthesis is performed easily, which is preferable.

A structure of another organic compound is represented by General Formula (G2).

(G2)



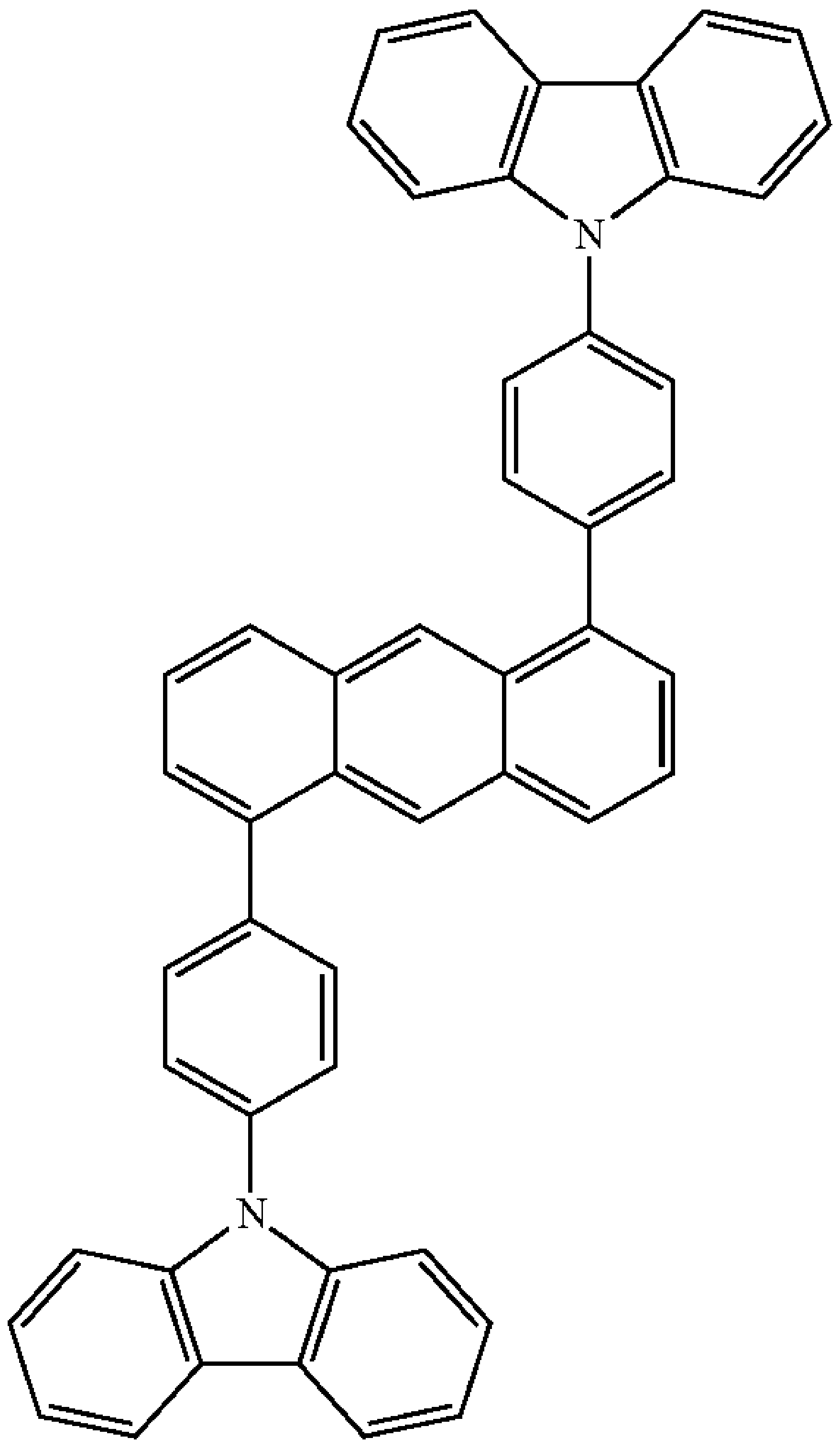
(G2-1)



Note that either of A^1 and A^2 in General Formula (G2) is a substituent represented by General Formula (G2-1), and the other is hydrogen or another substituent. Furthermore, General Formula (G2) may include one or more substituents. When General Formula (G2) includes the one or more substituents and either of A^1 and A^2 is the another substituent, they independently represent an alkyl group having 1 to 6 carbon atoms, a cycloalkyl group having 1 to 6 carbon atoms, an alkylphenyl group, or a phenyl group.

Specific examples of the structural formulae of the above-described organic compound are shown below. Note that the present invention is not limited to these examples.

(100)



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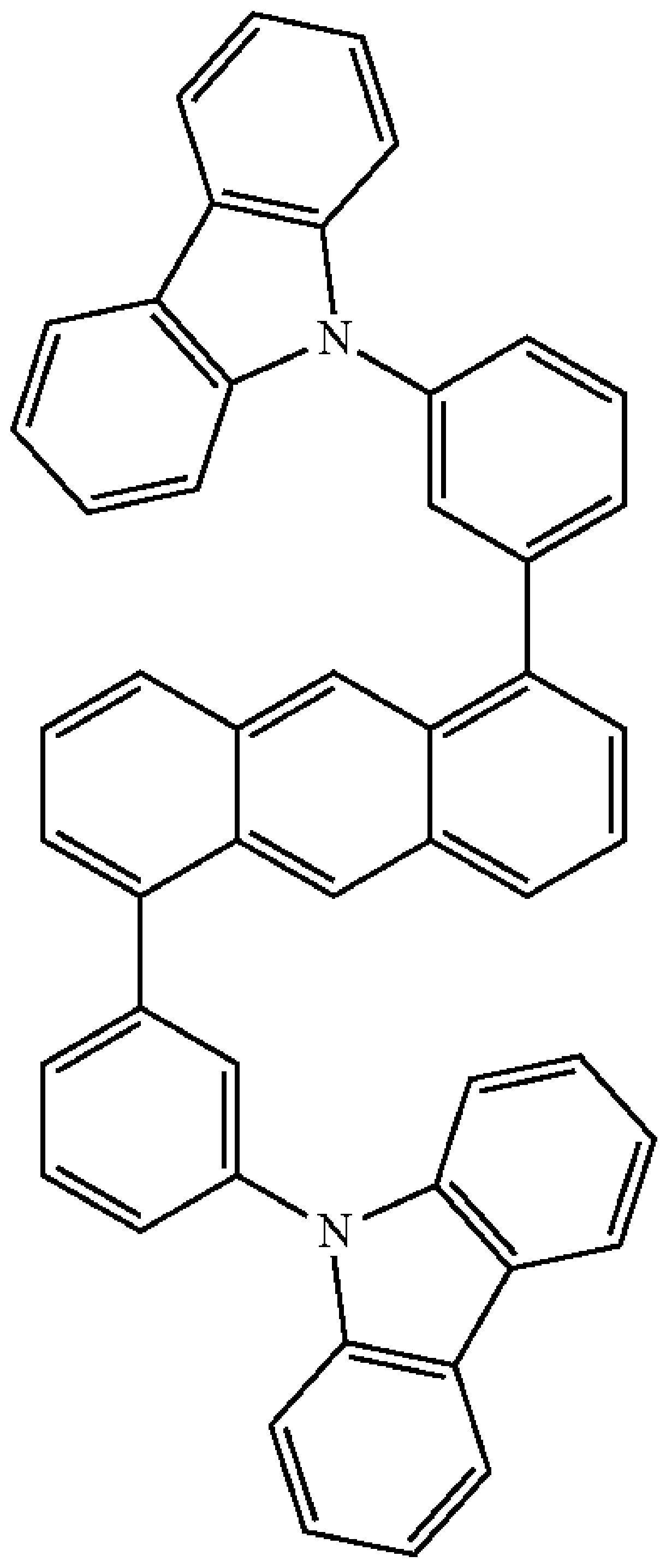

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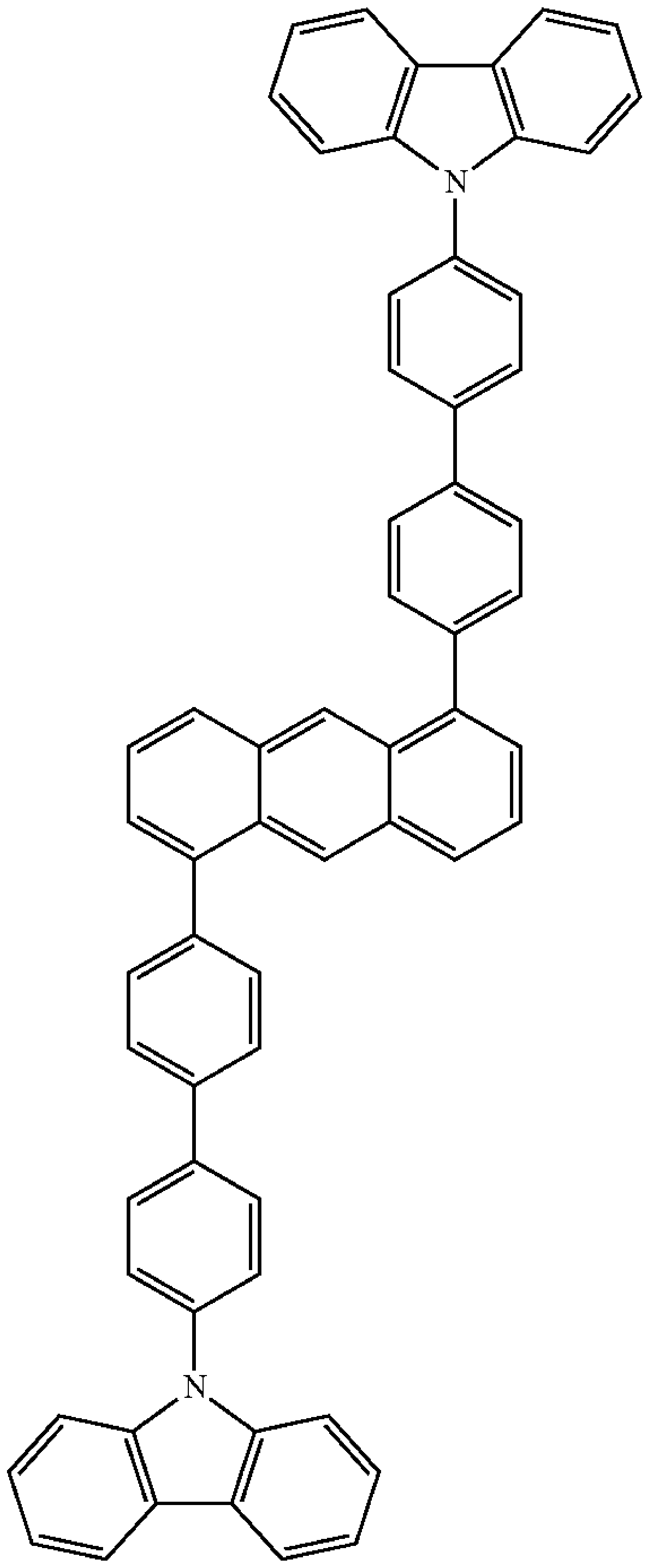

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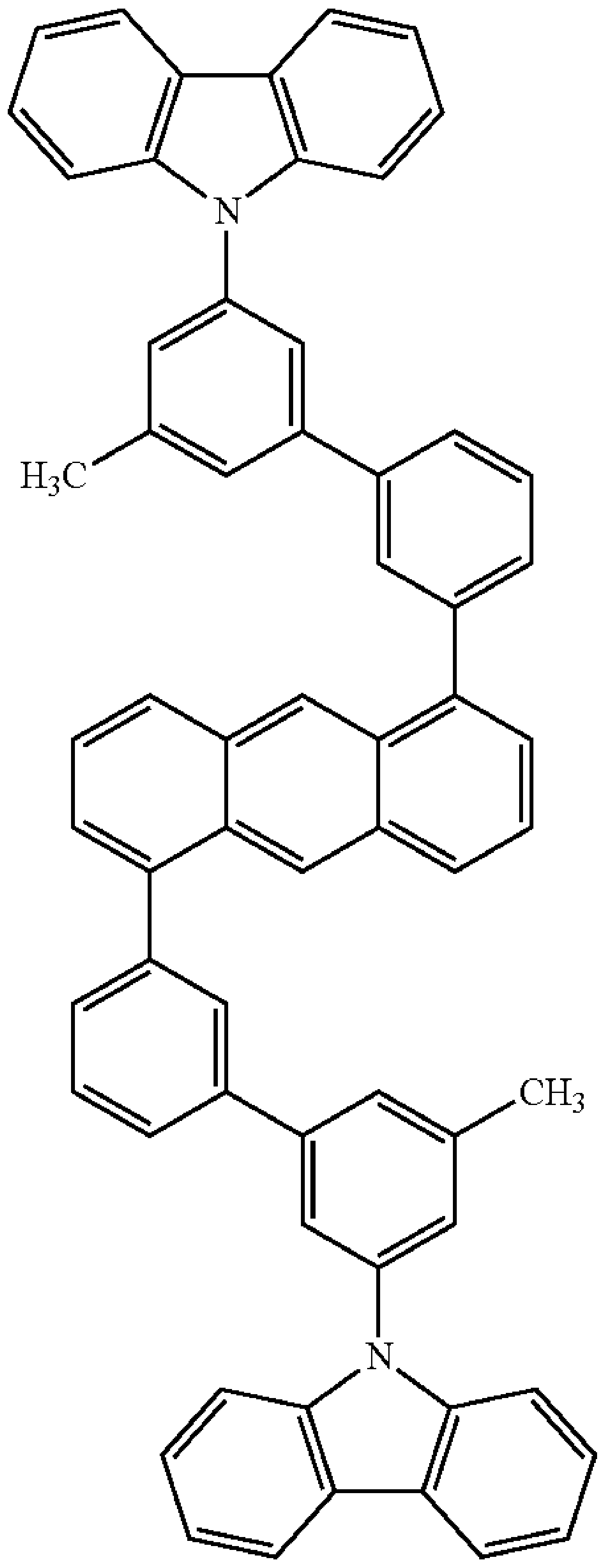

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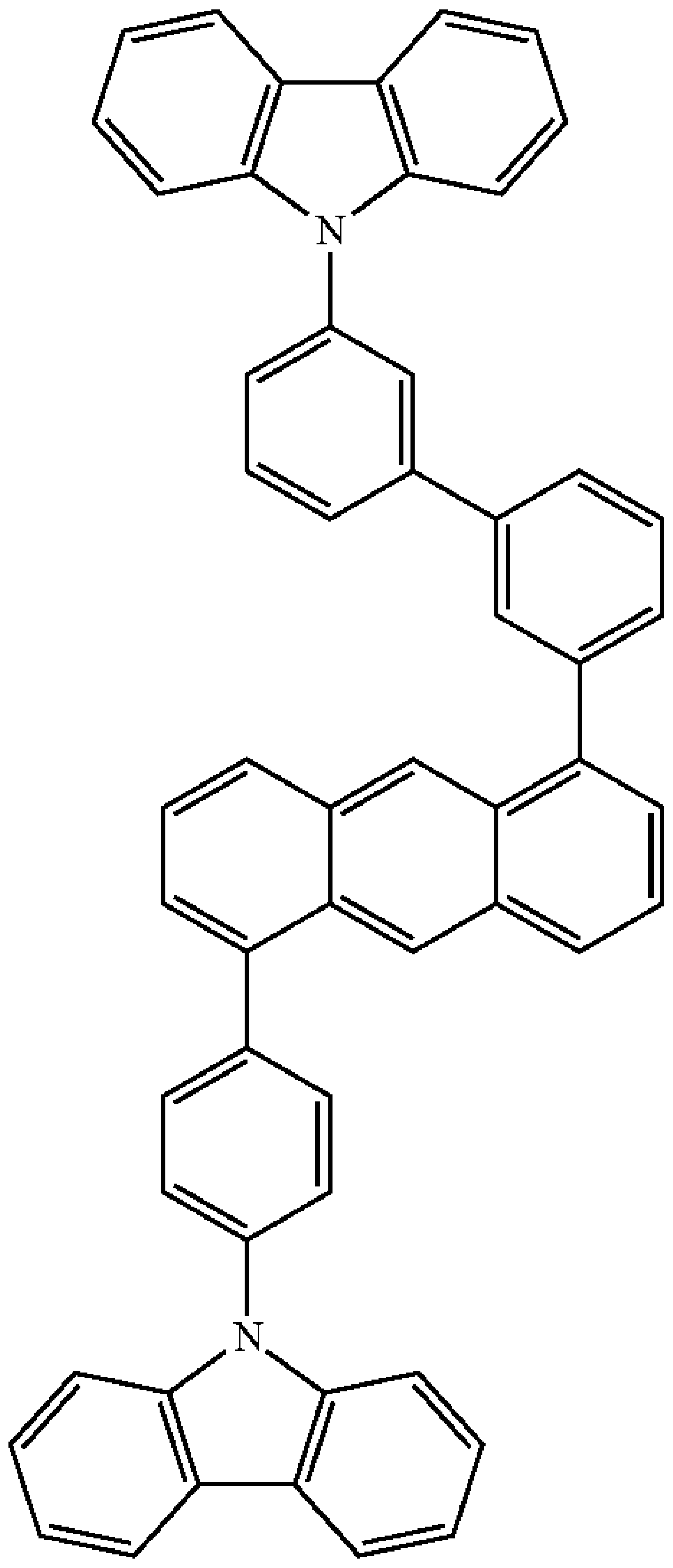

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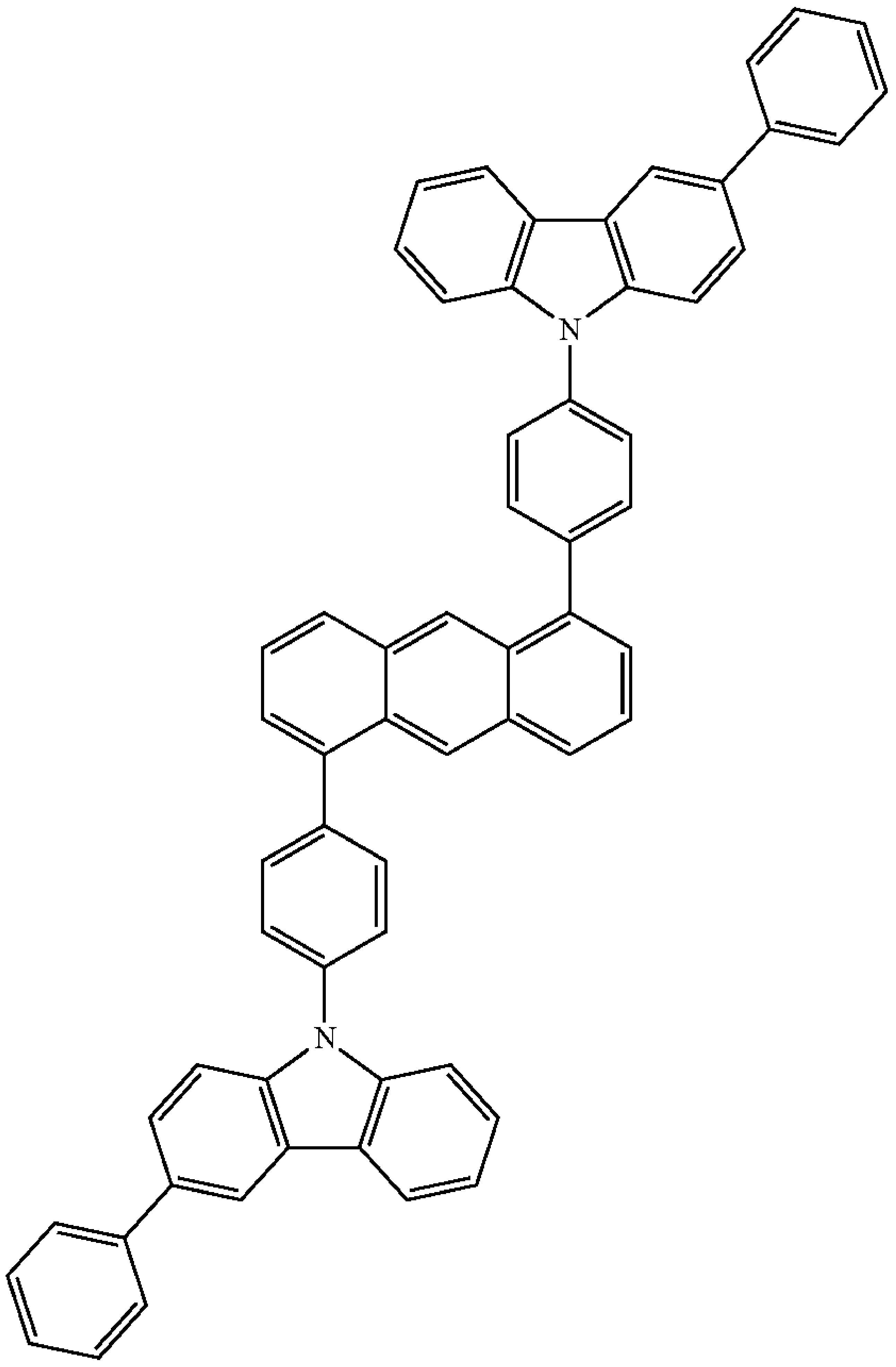

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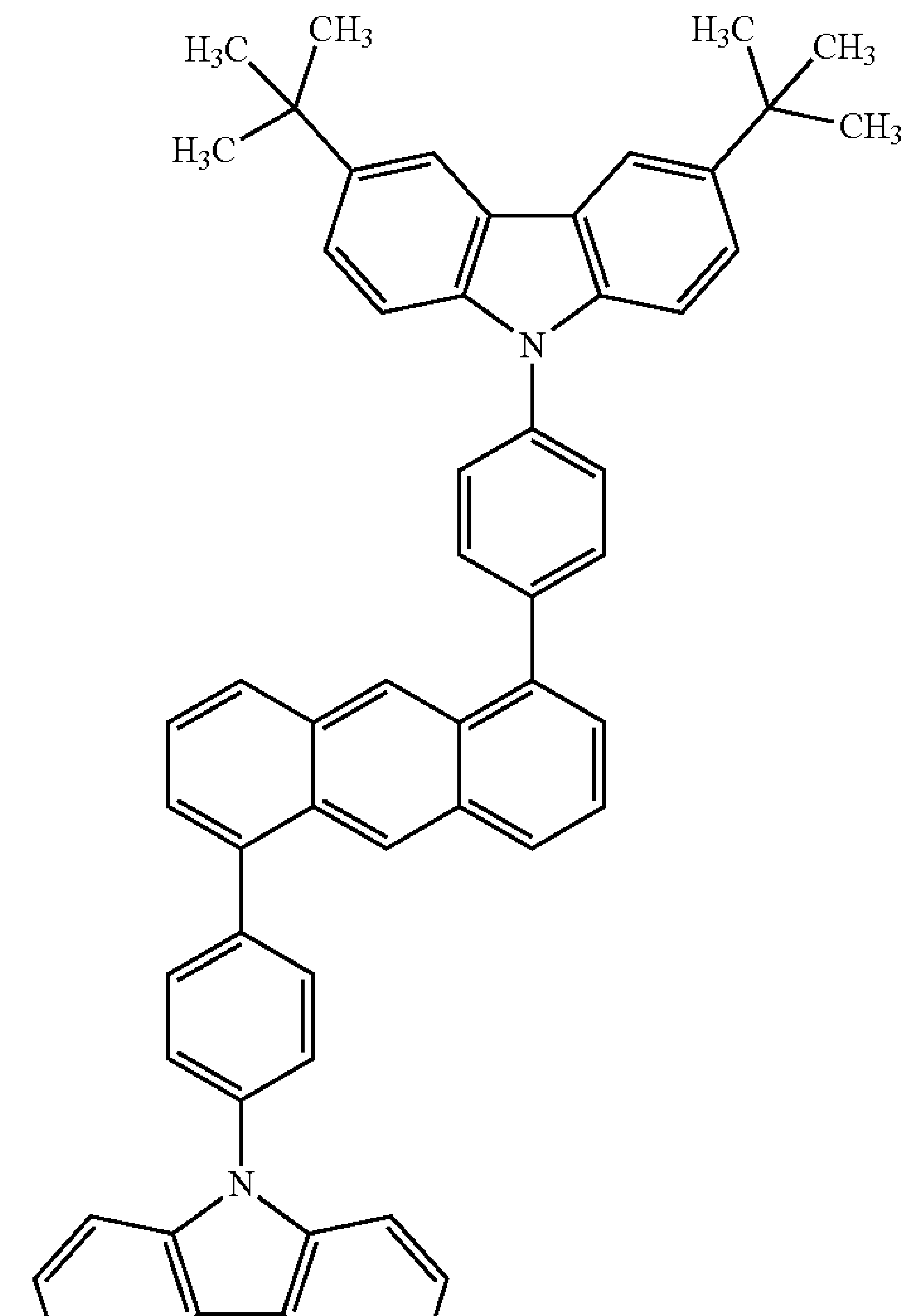

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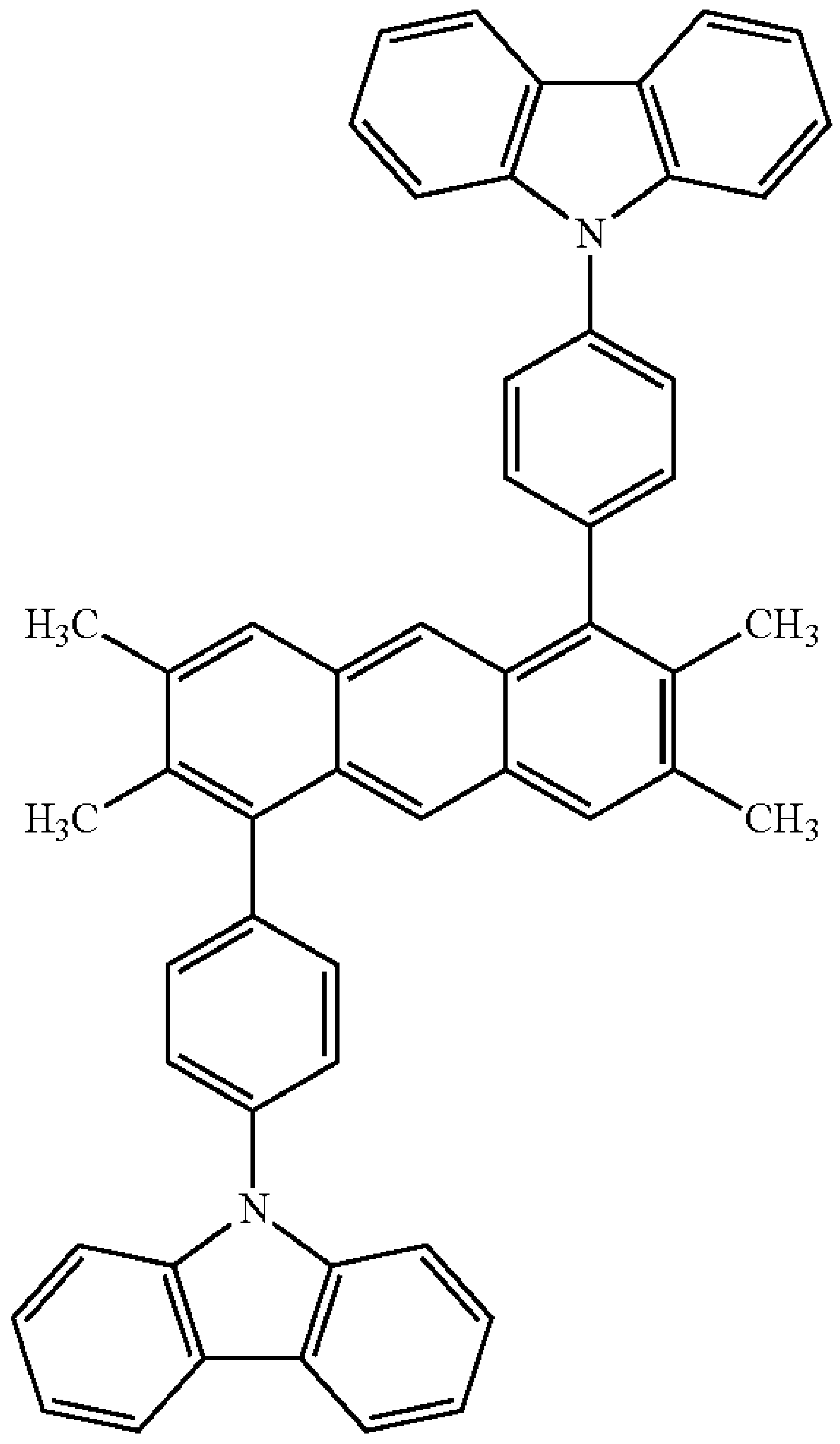

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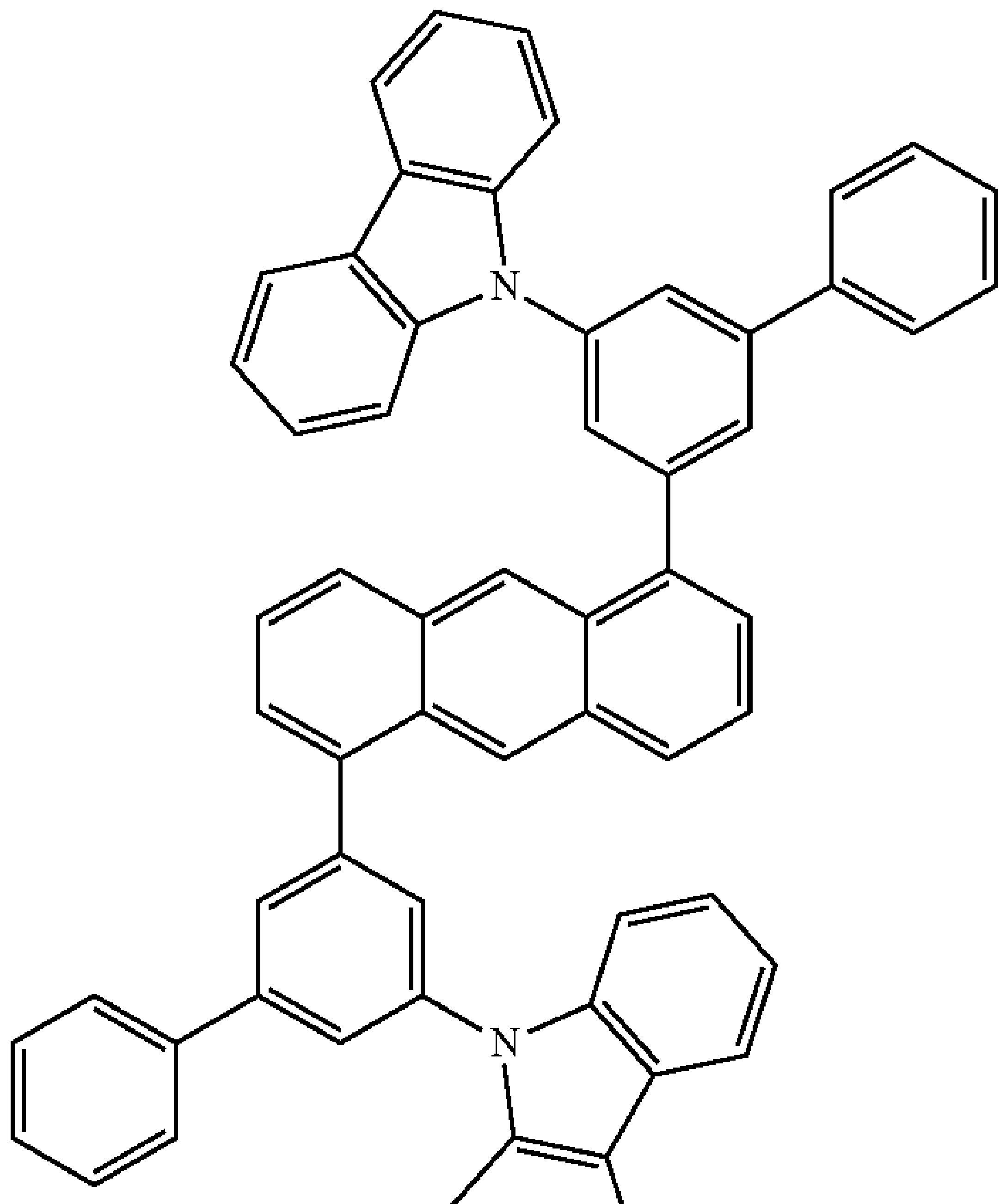

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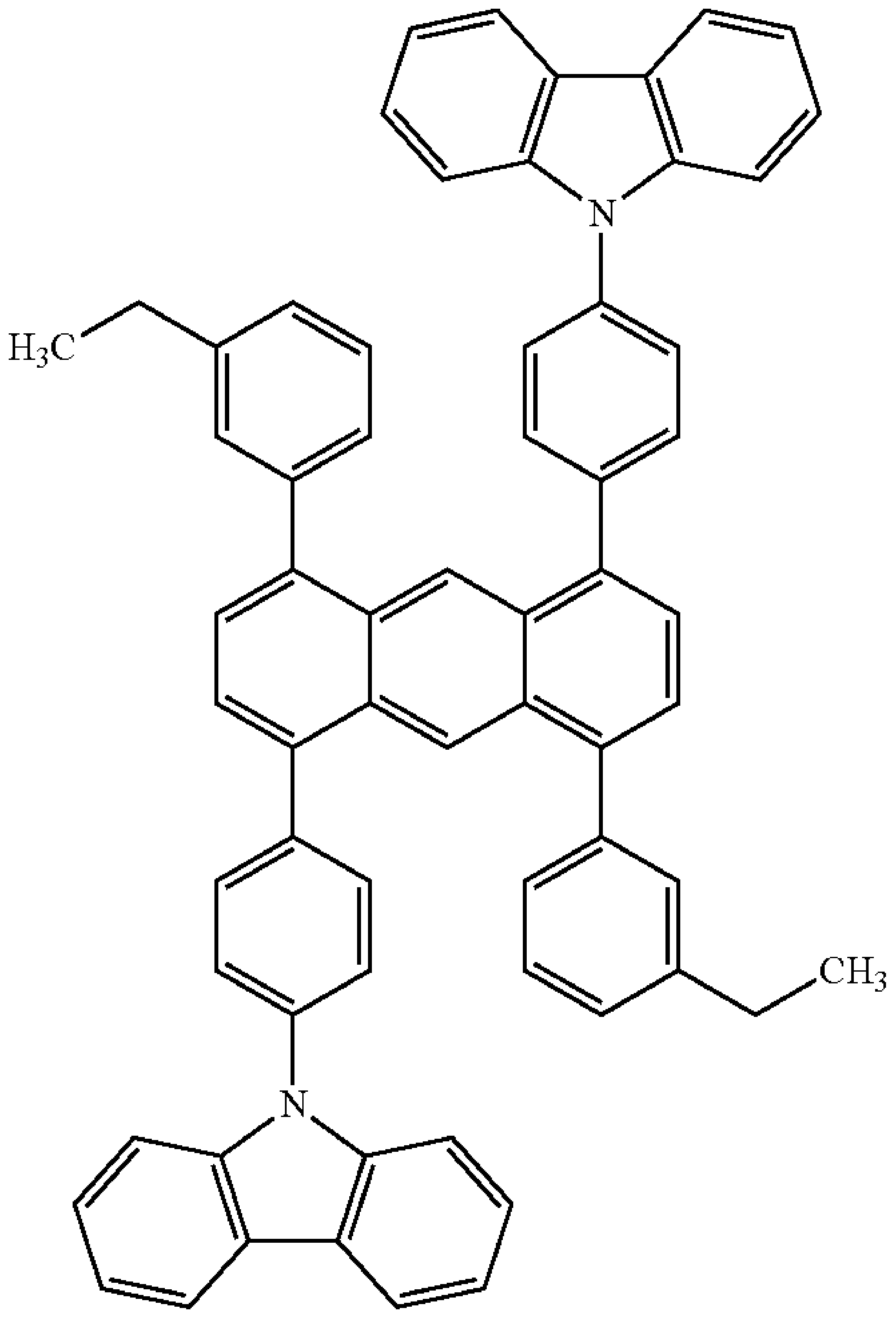

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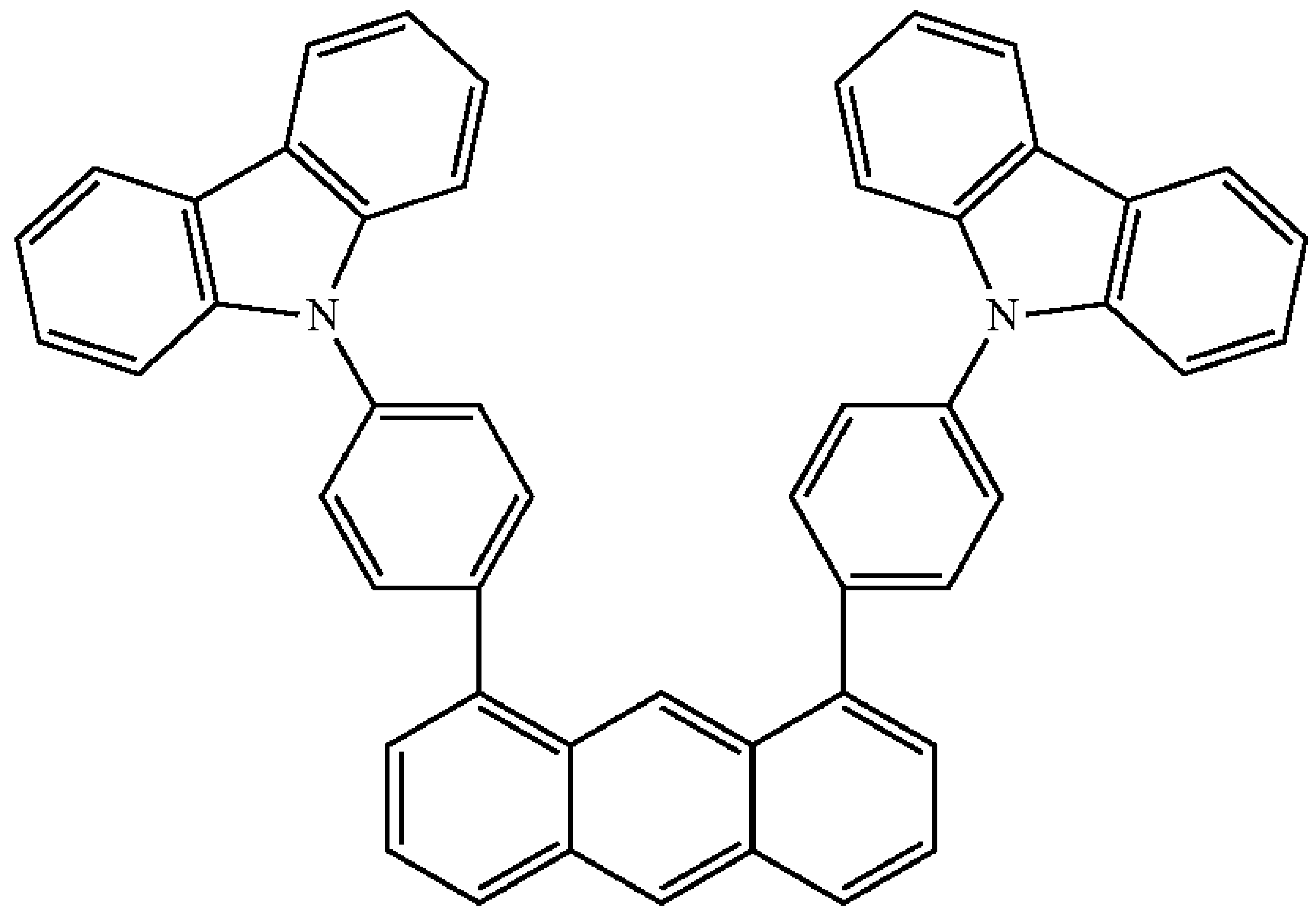

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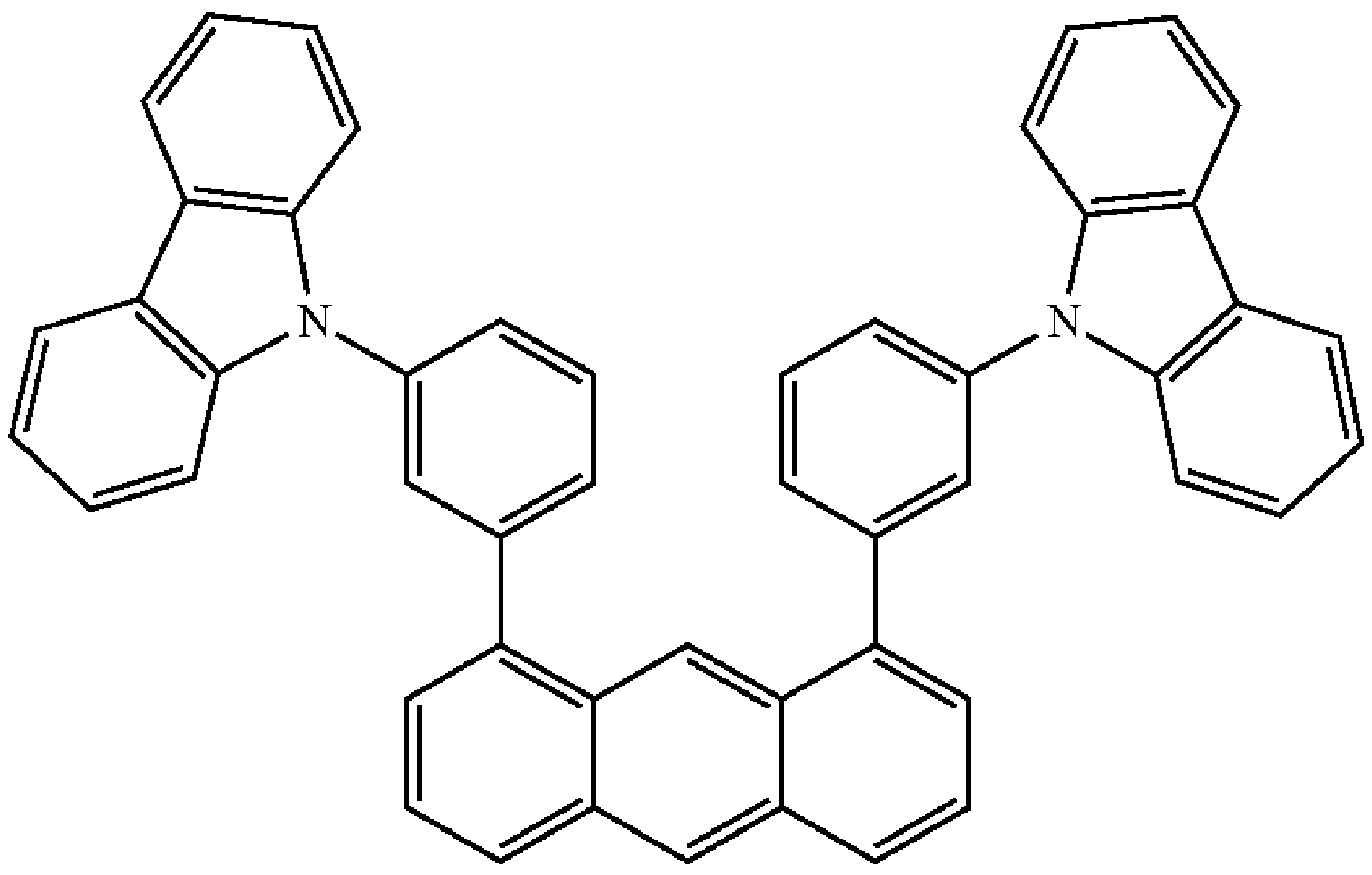

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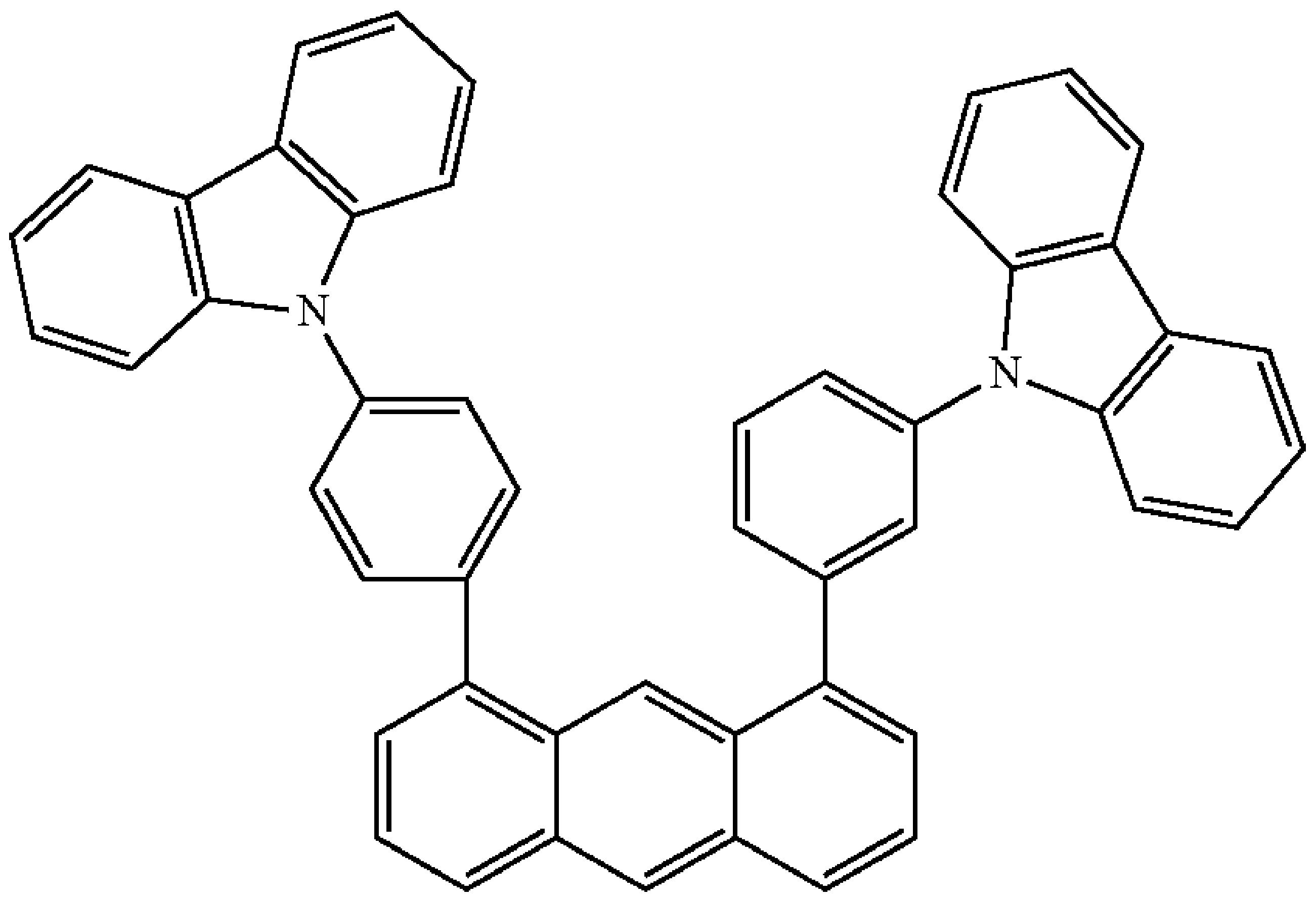

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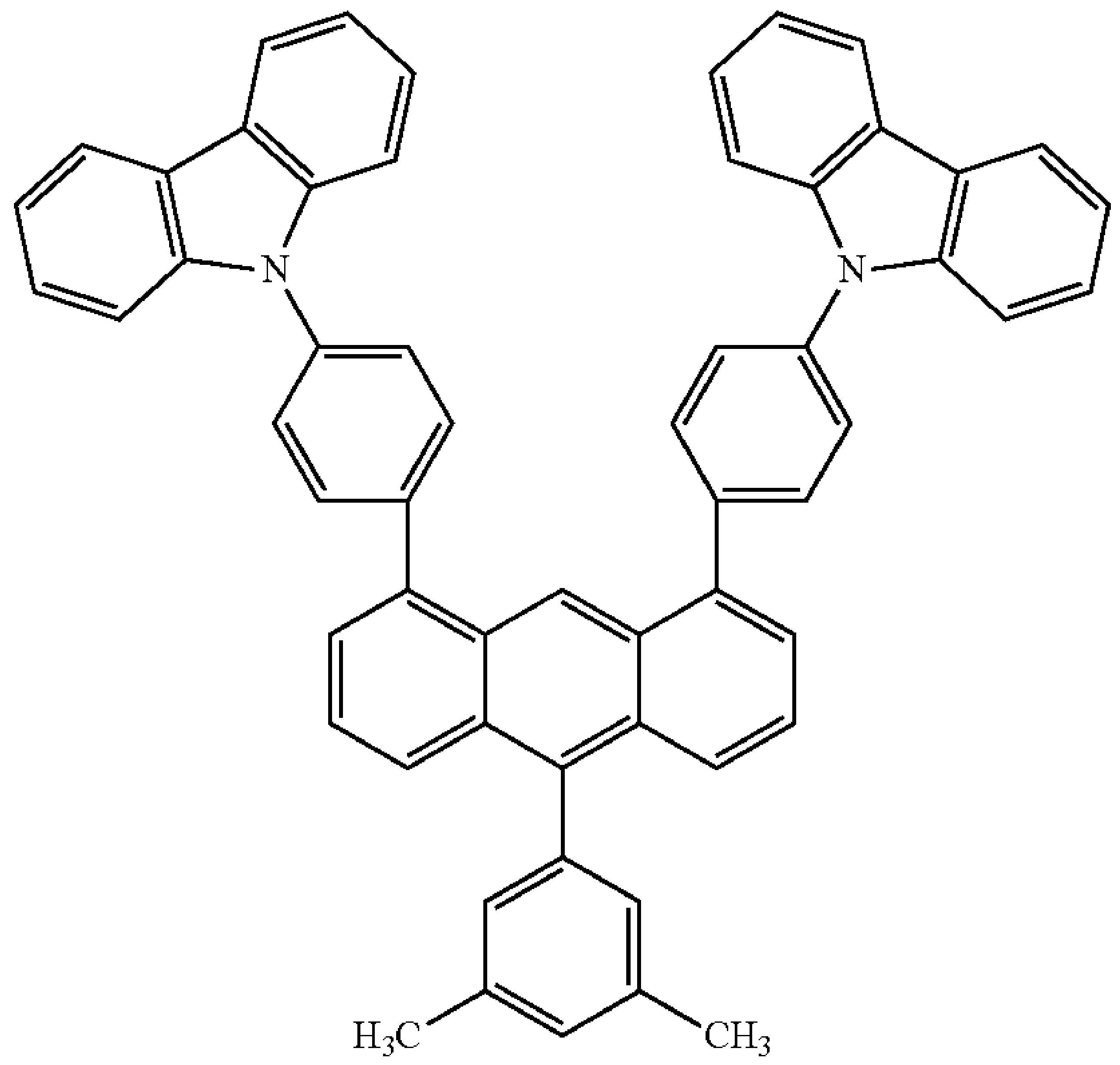

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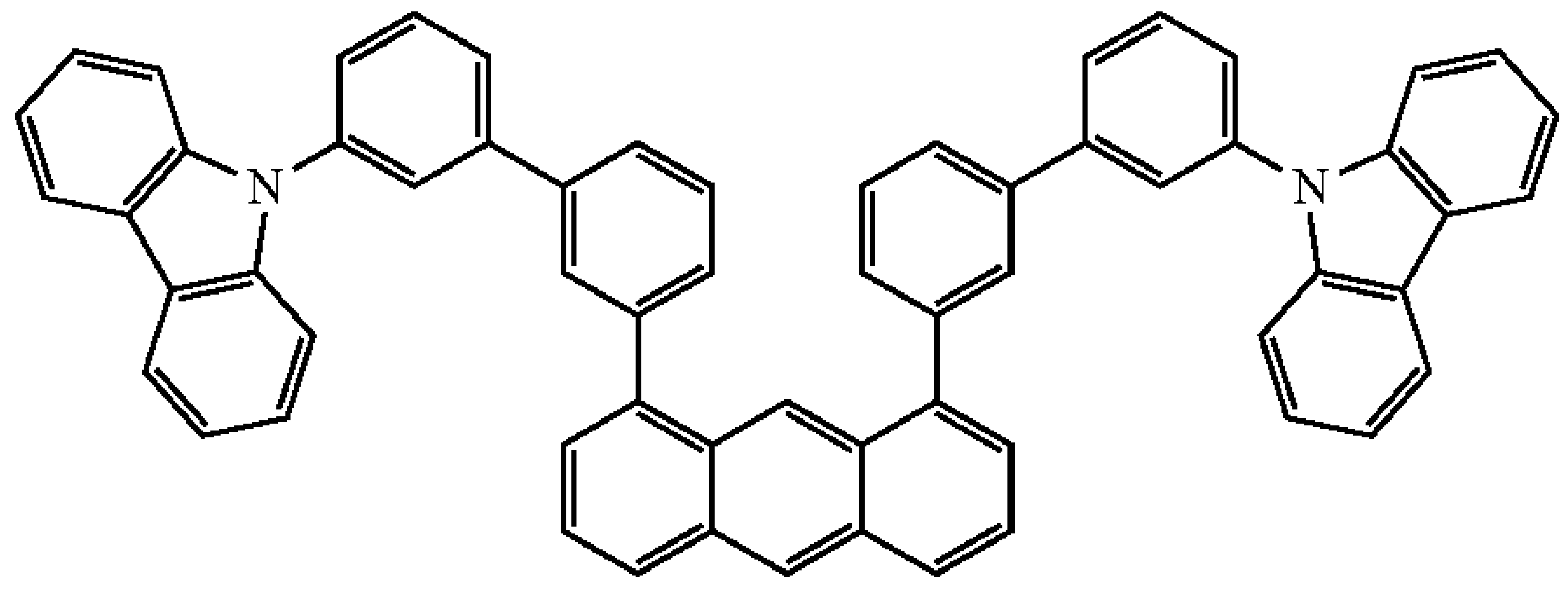

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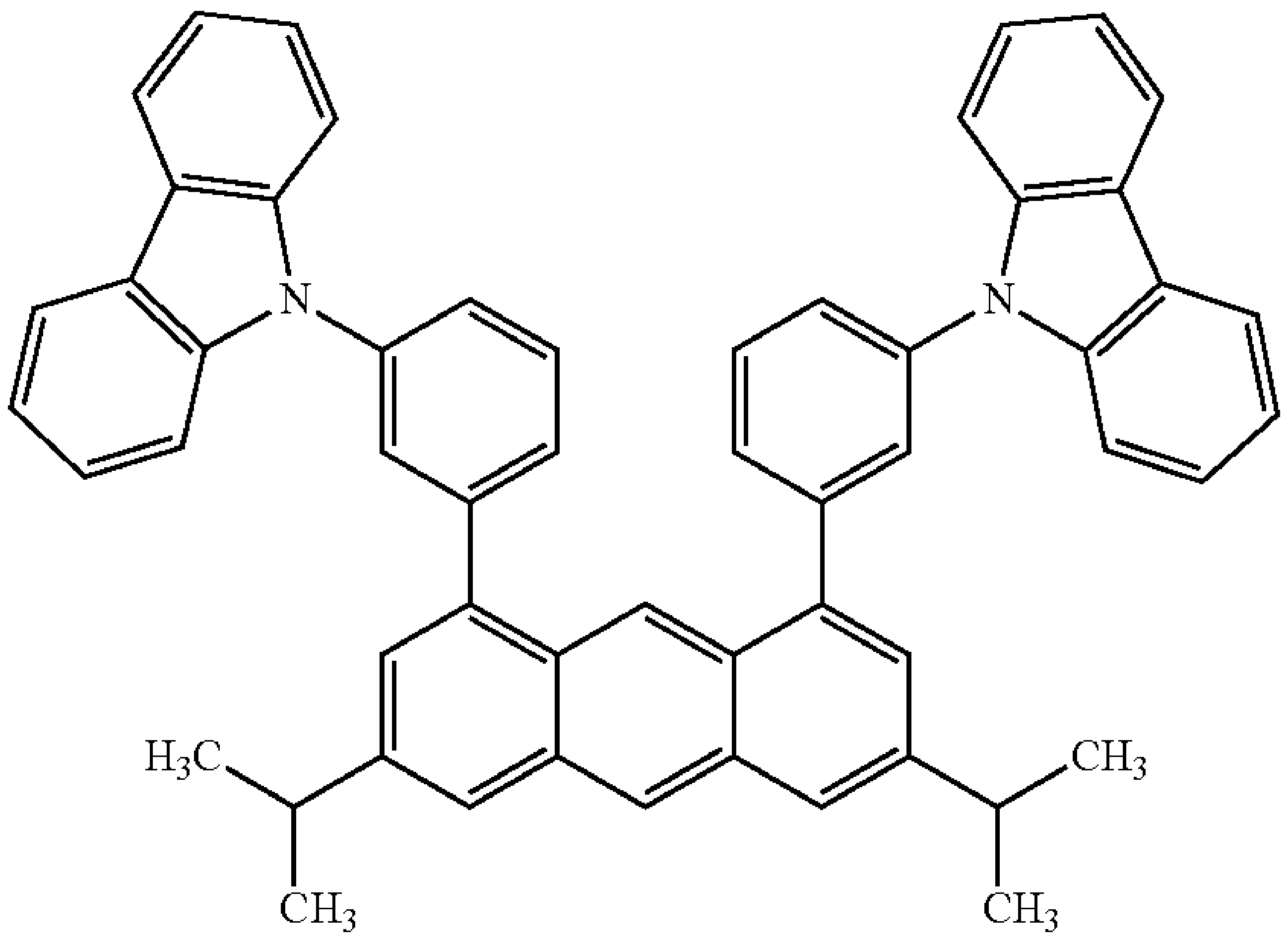
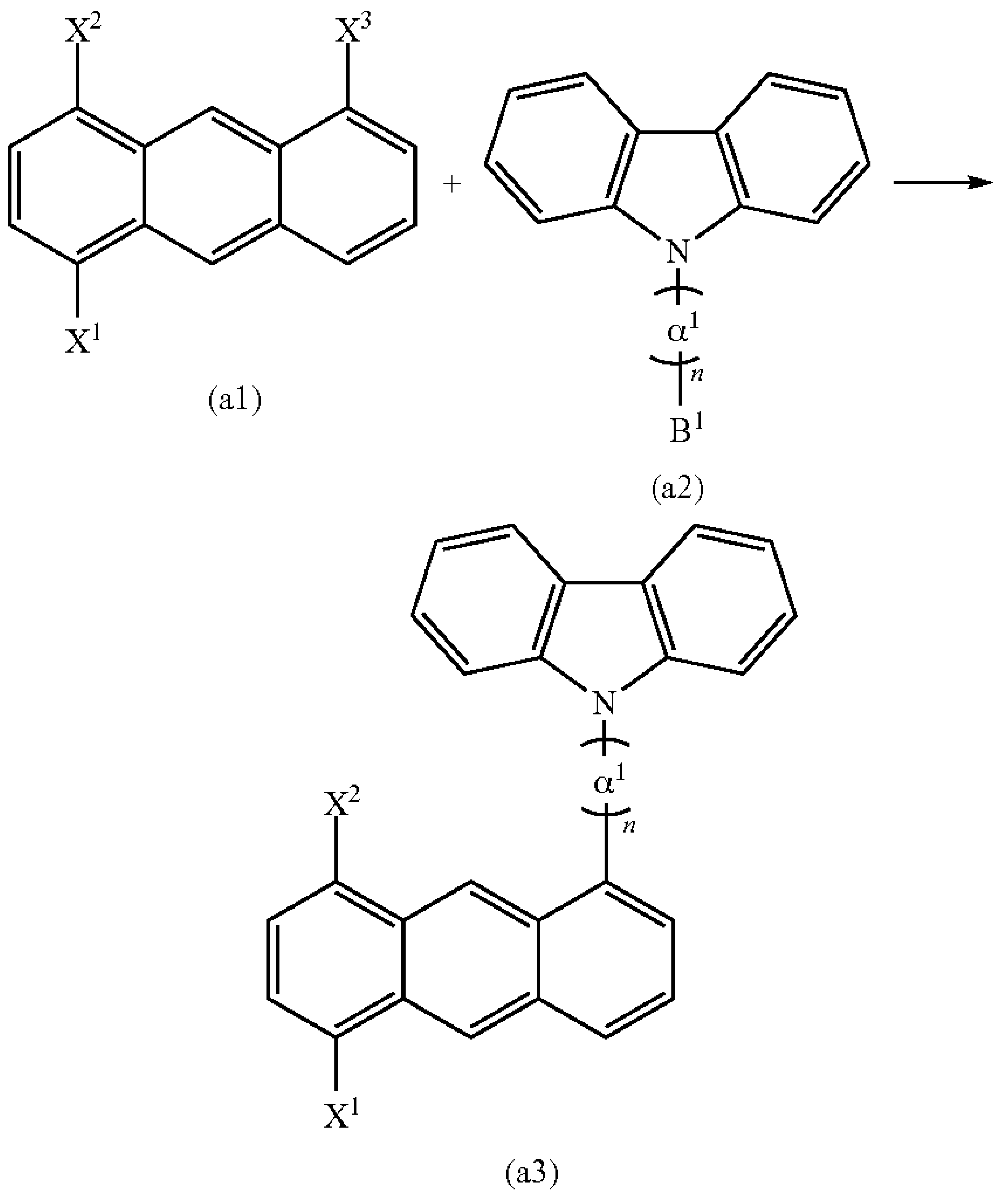


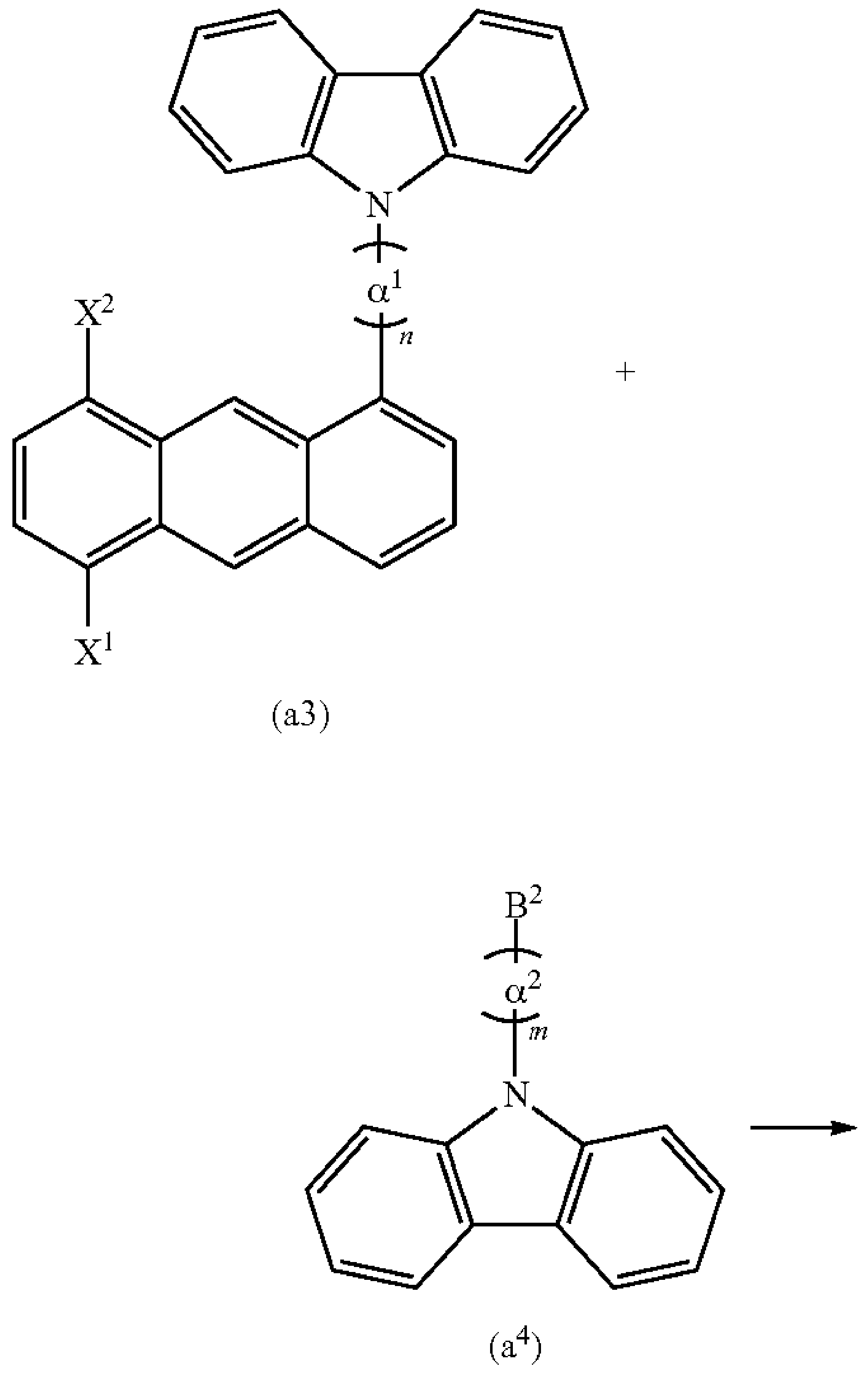
Examples of a method for synthesizing the organic compound represented by General Formula (G1) and General

Formula (G1-1) are described referring to Synthesis Schemes (F1-1) and (F1-2). That is, by application of coupling reactions shown in Synthesis Schemes (F1-1) and (F1-2), the organic compound represented by General Formula (G1) and General Formula (G1-1) can be synthesized. As in the above case, either of A^1 and A^2 in General Formula (G1) is the substituent represented by General Formula (G1-1), and the other is hydrogen or another substituent.

(F1-1)



(F1-2)



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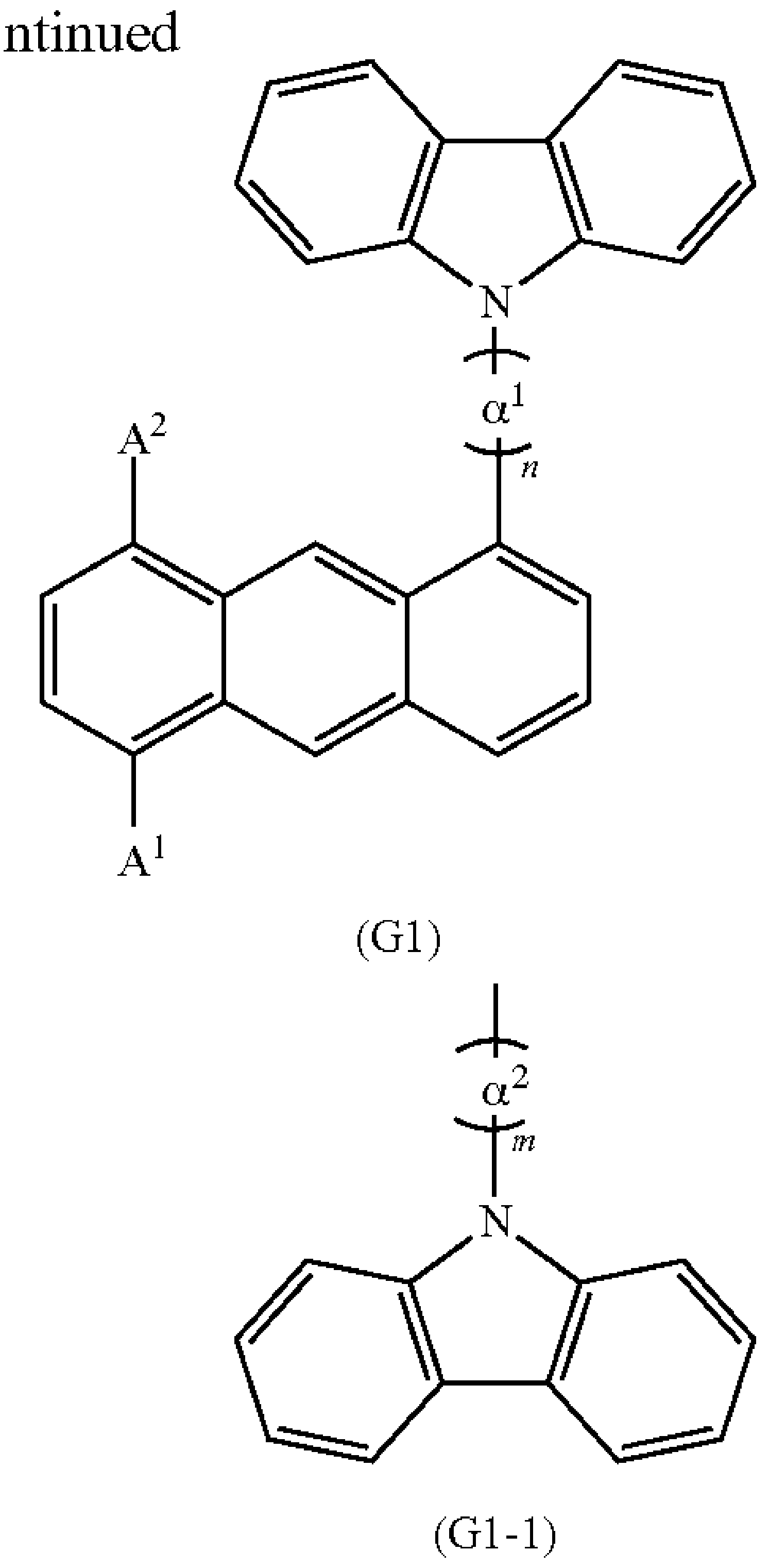


In Synthesis Schemes (F1-1) and (F1-2), either of X^1 and X^2 and X^3 represent halogen. Specifically, iodine, bromine, and chlorine have higher reactivity in this order and are preferred in this order. B^1 and B^2 each represent a boron compound; specifically, represent boronic acid or alkoxy boron. Note that an aryl aluminum compound, an aryl zirconium compound, an aryl zinc compound, an aryl tin compound, or the like may also be used. In addition, α^1 and α^2 individually represent a substituted or unsubstituted phenylene group. Note that n and m individually represent 1 or 2.

There are a variety of reaction conditions for the coupling reactions in Synthesis Schemes (F1-1) and (F1-2). As an example, a synthesis method using a metal catalyst in the presence of a base, such as a Suzuki-Miyaura reaction, can be employed. In the above synthesis method, the synthesis is carried out in two steps of a synthesis step represented by Synthesis Scheme (F1-1) and a synthesis step represented by Synthesis Scheme (F1-2). However, in the case where α^1 in a compound (a2) and α^2 in a compound (a4) are the same and n in the compound (a2) and m in the compound (a4) are the same, two or more equivalents of the compound (a2) may be added to the compound (a1), in which case the organic compound can be easily synthesized in one step.

Although the example of a method for synthesizing the organic compound is described above, the present invention is not limited thereto and any other synthesis method may be employed.

The above-described organic compound can be used alone or in combination with a light-emitting substance (guest), another organic compound, or the like in a light-emitting element.

In addition, the above-described organic compound can be used in an organic thin film solar cell. More specifically, the organic compound can be used in a carrier-transport layer or a carrier-injection layer since the organic compound has a carrier-transport property. In addition, a mixed layer of the organic compound and an acceptor substance can be used as a charge generation layer. The organic compound can be photoexcited and hence can be used for a power generation layer.

In Embodiment 2, one embodiment of the present invention has been described. Other embodiments of the present invention are described in Embodiments 3 to 12 as follows. Note that one embodiment of the present invention is not limited to the above examples. That is, since various embodiments of the present invention are disclosed in this embodiment and other embodiments, one embodiment of the present invention is not limited to a specific embodiment.

Embodiment 3

In Embodiment 3, a light-emitting element of the present invention will be described with reference to FIGS. **4**A and **4**B.

In the light-emitting element described in this embodiment, an EL layer **102** including a light-emitting layer **113** is provided between a pair of electrodes (a first electrode (anode) **101** and a second electrode (cathode) **103**). The EL layer **102** includes, in addition to the light-emitting layer **113**, a hole-injection layer **111**, a hole-transport layer **112**, an electron-transport layer **114**, an electron-injection layer **115**, and the like.

When a voltage is applied to the light-emitting element, holes injected from the first electrode **101** side and electrons injected from the second electrode **103** side recombine in the light-emitting layer **113**; with energy generated by the recombination, a light-emitting substance such as an organometallic complex that is contained in the light-emitting layer **113** emits light.

The hole-injection layer **111** in the EL layer **102** can inject holes into the hole-transport layer **112** or the light-emitting layer **113** and can be formed of, for example, a substance having a high hole-transport property and a substance having an acceptor property, in which case electrons are extracted from the substance having a high hole-transport property by the substance having an acceptor property to generate holes. Thus, holes are injected from the hole-injection layer **111** into the light-emitting layer **113** through the hole-transport layer **112**. For the hole-injection layer **111**, a substance having a high hole-injection property can also be used. For example, molybdenum oxide, vanadium oxide, ruthenium oxide, tungsten oxide, manganese oxide, or the like can be used. Alternatively, the hole-injection layer **111** can be formed using a phthalocyanine-based compound such as phthalocyanine (abbreviation: H_2Pc) and copper phthalocyanine (CuPc), an aromatic amine compound such as 4,4'-bis[N-(4-diphenylaminophenyl)-N-phenylamino]biphenyl (abbreviation: DPAB) and N,N'-bis{4-[bis(3-methylphenyl)amino]phenyl}-N,N'-diphenyl-(1,1'-biphenyl)-4,4'-diamine (abbreviation: DNTPD), or a high molecular compound such as poly(3,4-ethylenedioxythiophene)/poly(styrenesulfonic acid) (abbreviation: PEDOT/PSS).

A preferred specific example in which the light-emitting element described in this embodiment is fabricated is described below.

For the first electrode (anode) **101** and the second electrode (cathode) **103**, a metal, an alloy, an electrically conductive compound, a mixture thereof, and the like can be used. Specific examples are indium oxide-tin oxide (indium tin oxide), indium oxide-tin oxide containing silicon or silicon oxide, indium oxide-zinc oxide (indium zinc oxide), indium oxide containing tungsten oxide and zinc oxide, gold (Au), platinum (Pt), nickel (Ni), tungsten (W), chromium (Cr), molybdenum (Mo), iron (Fe), cobalt (Co), copper (Cu), palladium (Pd), and titanium (Ti). In addition, an element belonging to Group 1 or Group 2 of the periodic table, for example, an alkali metal such as lithium (Li) or cesium (Cs), an alkaline earth metal such as calcium (Ca) or strontium (Sr), magnesium (Mg), and an alloy containing such an element (MgAg or AlLi); a rare earth metal such as europium (Eu) or ytterbium (Yb) and an alloy containing such an element; a graphene compound such as graphene or graphene oxide; and the like can be used. The first electrode (anode) **101** and the second electrode (cathode) **103** can be formed by, for example, a sputtering method or an evaporation method (including a vacuum evaporation method).

As the substance having a high hole-transport property which is used for the hole-injection layer **111** and the hole-transport layer **112**, any of a variety of organic compounds such as aromatic amine compounds, carbazole derivatives, aromatic hydrocarbons, and high molecular compounds (e.g., oligomers, dendrimers, or polymers) can be used. The organic compound used for the composite material is preferably an organic compound having a high hole-transport property. Specifically, a substance having a hole mobility of 1×10^{-6} cm^2/Vs or more is preferably used. The layer formed using the substance having a high hole-transport property is not limited to a single layer and may be formed by stacking two or more layers. Organic compounds that can be used as the substance having a hole-transport property are specifically given below.

The substance used for the hole-transport layer **112** preferably has higher S_1 and T_1 levels than the light-emitting layer **113** that is adjacent to the hole-transport layer **112** because diffusion of excitation energy to the hole-transport layer **112** can be suppressed. Furthermore, the substance used for the hole-transport layer **112** preferably has a higher LUMO level (a larger value) than the light-emitting layer **113** that is adjacent to the hole-transport layer **112** because passage of electrons through the light-emitting layer **113** to the hole-transport layer **112** can be suppressed. Furthermore, a HOMO level of the substance used for the hole-transport layer **112** is preferably deeper (a smaller value) than or substantially equal to the HOMO level of the light-emitting layer **113** that is adjacent to the hole-transport layer **112** because easier hole-injection into the light-emitting layer **113** can be achieved. Organic compounds that can be used as the substance having a hole-transport property are specifically given below.

Examples of the aromatic amine compounds are N,N'-di(p-tolyl)-N,N'-diphenyl-p-phenylenediamine (abbreviation: DTDPPA), 4,4'-bis[N-(4-diphenylaminophenyl)-N-phenylamino]biphenyl (abbreviation: DPAB), DNTPD, 1,3,5-tris[N-(4-diphenylaminophenyl)-N-phenylamino]benzene (abbreviation: DPA3B), 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (abbreviation: NPB or α-NPD), N,N'-bis(3-methylphenyl)-N,N'-diphenyl-[1,1'-biphenyl]-4,4'-diamine (abbreviation: TPD), 4,4',4"-tris(carbazol-9-yl)triphenylamine (abbreviation: TCTA), 4,4',4"-tris(N,N-diphenylamino)triphenylamine (abbreviation: TDATA), 4,4',4"-tris[N-(3-methylphenyl)-N-phenylamino]triphenylamine (abbreviation: MTDATA), and 4,4'-bis[N-(spiro-9,9'-bifluoren-2-yl)-N-phenylamino]biphenyl (abbreviation: BSPB), and the like.

Specific examples of carbazole derivatives are 3-[N-(9-phenylcarbazol-3-yl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzPCA1), 3,6-bis[N-(9-phenylcarbazol-3-yl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzPCA2), 3-[N-(1-naphthyl)-N-(9-phenylcarbazol-3-yl)amino]-9-phenylcarbazole (abbreviation: PCzPCN1), and the like. Other examples are 4,4'-di(N-carbazolyl)biphenyl (abbreviation: CBP), 1,3,5-tris[4-(N-carbazolyl)phenyl]benzene (abbreviation: TCPB), 9-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazole (abbreviation: CzPA), 1,4-bis[4-(N-carbazolyl)phenyl]-2,3,5,6-tetraphenylbenzene, and the like.

Examples of aromatic hydrocarbons are 2-tert-butyl-9,10-di(2-naphthyl)anthracene (abbreviation: t-BuDNA), 2-tert-butyl-9,10-di(1-naphthyl)anthracene, 9,10-bis(3,5-diphenylphenyl)anthracene (abbreviation: DPPA), 2-tert-butyl-9,10-bis(4-phenylphenyl)anthracene (abbreviation: t-BuDBA), 9,10-di(2-naphthyl)anthracene (abbreviation: DNA), 9,10-diphenylanthracene (abbreviation: DPAnth), 2-tert-butylanthracene (abbreviation: t-BuAnth), 9,10-bis(4-methyl-1-naphthyl)anthracene (abbreviation: DMNA), 2-tert-butyl-9,10-bis[2-(1-naphthyl)phenyl]anthracene, 9,10-bis[2-(1-naphthyl)phenyl]anthracene, 2,3,6,7-tetramethyl-9,10-di(1-naphthyl)anthracene, 2,3,6,7-tetramethyl-9,10-di(2-naphthypanthracene, 9,9'-bianthryl, 10,10'-diphenyl-9,9'-bianthryl, 10,10'-bis(2-phenylphenyl)-9,9'-bianthryl, 10,10'-bis[(2,3,4,5,6-pentaphenyl)phenyl]-9,9'-bianthryl, anthracene, tetracene, rubrene, perylene, 2,5,8,11-tetra(tert-butyl)perylene, and the like. Besides, pentacene, coronene, or the like can also be used. The aromatic hydrocarbon which has a hole mobility of 1×10^{-6} cm^2/Vs or more and which has 14 to 42 carbon atoms is particularly preferable. The aromatic hydrocarbons may have a vinyl skeleton. Examples of the aromatic hydrocarbon having a vinyl group are 4,4'-bis(2,2-diphenylvinyl)biphenyl (abbreviation: DPVBi), 9,10-bis[4-(2,2-diphenylvinyl)phenyl]anthracene (abbreviation: DPVPA), and the like.

A high molecular compound such as poly(N-vinylcarbazole) (abbreviation: PVK), poly(4-vinyltriphenylamine) (abbreviation: PVTPA), poly[N-(4-{N'-[4-(4-diphenylamino)phenyl]phenyl-N'-phenylamino}phenyl)methacrylamide] (abbreviation: PTPDMA), or poly[N,N'-bis(4-butylphenyl)-N,N'-bis(phenyl)benzidine] (abbreviation: Poly-TPD) can also be used.

Examples of the substance having an acceptor property which is used for the hole-injection layer **111** and the hole-transport layer **112** are compounds having an electron-withdrawing group (a halogen group or a cyano group) such as 7,7,8,8-tetracyano-2,3,5,6-tetrafluoroquinodimethane (abbreviation: F_4-TCNQ), chloranil, and 2,3,6,7,10,11-hexacyano-1,4,5,8,9,12-hexaazatriphenylene (HAT-CN). In particular, a compound in which electron-withdrawing groups are bonded to a condensed aromatic ring having a plurality of heteroatoms, like HAT-CN, is thermally stable and preferable. Oxides of metals belonging to Groups 4 to 8 of the periodic table can be given. Specifically, vanadium oxide, niobium oxide, tantalum oxide, chromium oxide, molybdenum oxide, tungsten oxide, manganese oxide, and rhenium oxide are preferable because of their high electron-accepting properties. Among these, molybdenum oxide is especially preferable because it is stable in the air, has a low hygroscopic property, and is easy to handle.

The light-emitting layer **113** is a layer containing a light-emitting substance (guest material). Examples of the light-emitting substance include a light-emitting substances that convert singlet excitation energy into luminescence and light-emitting substances that convert triplet excitation energy into luminescence. In the case of a structure in which triplet excitons are converted into singlet excitons by TTA so that emission efficiency of the singlet excitons is improved as described in Embodiment 1, a light-emitting substance that converts singlet excitation energy into luminescence is preferably used. As an example of the light-emitting substance that converts singlet excitation energy into luminescence, a substance that emits fluorescence (fluorescent compound) can be given.

Examples of the substance that emits fluorescence are N,N'-bis[4-(9H-carbazol-9-yl)phenyl]-N,N'-diphenylstilbene-4,4'-diamine (abbreviation: YGA2S), 4-(9H-carbazol-9-yl)-4'-(10-phenyl-9-anthryl)triphenylamine (abbreviation: YGAPA), 4-(9H-carbazol-9-yl)-4'-(9,10-diphenyl-2-anthryl)triphenylamine (abbreviation: 2YGAPPA), N,9-diphenyl-N-[4-(10-phenyl-9-anthryl)phenyl]-9H-carbazol-3-amine (abbreviation: PCAPA), perylene, 2,5,8,11-tetra(tert-butyl)perylene (abbreviation: TBP), 4-(10-phenyl-9-anthryl)-4'-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBAPA), N,N''-(2-tert-butylanthracene-9,10-diyldi-4,1-phenylene)bis[N,N',N'-triphenyl-1,4-phenylenediamine] (abbreviation: DPABPA), N,9-diphenyl-N-[4-(9,10-diphenyl-2-anthryl)phenyl]-9H-carbazol-3-amine (abbreviation: 2PCAPPA), N-[4-(9,10-diphenyl-2-anthryl)phenyl]-N,N',N'-triphenyl-1,4-phenylenediamine (abbreviation: 2DPAPPA), N,N,N',N',N'',N'',N''',N'''-octaphenyldibenzo[g,p]chrysene-2,7,10,15-tetraamine (abbreviation: DBC1), coumarin 30, N-(9,10-diphenyl-2-anthryl)-N,9-diphenyl-9H-carbazol-3-amine (abbreviation: 2PCAPA), N-[9,10-bis(1,1'-biphenyl-2-yl)-2-anthryl]-N,9-diphenyl-9H-carbazol-3-amine (abbreviation: 2PCABPhA), N-(9,10-diphenyl-2-anthryl)-N,N',N'-triphenyl-1,4-phenylenediamine (abbreviation: 2DPAPA), N-[9,10-bis(1,1'-biphenyl-2-yl)-2-anthryl]-N,N',N'-triphenyl-1,4-phenylenediamine (abbreviation: 2DPABPhA), 9,10-bis(1,1'-biphenyl-2-yl)-N-[4-(9H-carbazol-9-yl)phenyl]-N-phenylanthracen-2-amine (abbreviation: 2YGABPhA), N,N,9-triphenylanthracen-9-amine (abbreviation: DPhAPhA), coumarin 545T, N,N'-diphenylquinacridone (abbreviation: DPQd), rubrene, 5,12-bis(1,1'-biphenyl-4-yl)-6,11-diphenyltetracene (abbreviation: BPT), 2-(2-{2-[4-(dimethylamino)phenyl]ethenyl}-6-methyl-4H-pyran-4-ylidene)propanedinitrile (abbreviation: DCM1), 2-{2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: DCM2), N,N,N',N'-tetrakis(4-methylphenyl)tetracene-5,11-diamine (abbreviation: p-mPhTD), 7,14-diphenyl-N,N,N',N'-tetrakis(4-methylphenyl)acenaphtho[1,2-α]fluoranthene-3,10-diamine (abbreviation: p-mPhAFD), 2-{2-isopropyl-6-[2-(1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: DCJTI), 2-{2-tert-butyl-6-[2-(1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: DCJTB), 2-(2,6-bis{2-[4-(dimethylamino)phenyl]ethenyl}-4H-pyran-4-ylidene)propanedinitrile (abbreviation: BisDCM), 2-{2,6-bis[2-(8-methoxy-1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene}propanedinitrile (abbreviation: BisDCJTM), and the like.

In the case where the light-emitting substance that converts triplet excitation energy into luminescence is used in the light-emitting layer **113**, it is preferable that an organic compound (a host material) used with a light-emitting substance (referred to as a dopant or a guest material) have a higher probability of TTA. Specifically, an organic compound where the total of oscillator strengths (f) for transitions from the T_1 level of the organic compound to some T_n levels which are each higher than the T_1 level by less than 0.6 eV is 0.0015 or more, preferably 0.0020 or more is preferably used. That is, an organic compound in which the transition between the T_1 level and the T_n level easily occurs, and which has a higher probability of TTA caused by energy transfer by the Förster mechanism, is preferably used. As an example of the organic compound which has a higher probability of TTA, the organic compound described in Embodiment 2 can be used.

In the case where the light-emitting substance that converts triplet excitation energy into luminescence is used in the light-emitting element **113**, it seems that when the organic compound (the host material) used with the light-emitting substance (the dopant) is designed such that the T_1 level of the organic compound (the host material) is the lowest, the triplet excitation energy is collected at the host material and thus the probability of TTA is increased.

Furthermore, in the light-emitting layer **113** of the light-emitting element in this embodiment, not only a structure in which a substance that emits fluorescence (a fluorescence compound) is used for a light-emitting substance by utilizing TTA, but also a structure in which a light-emitting substance that converts triplet excitation energy into luminescence can be used together with the substance that emits fluorescence (a fluorescence compound). Examples of the light-emitting substance that converts triplet excitation energy into luminescence include a substance which emits phosphorescence (a phosphorescent compound) and a thermally activated delayed fluorescent (TADF) material which emits thermally activated delayed fluorescence. Note that "delayed fluorescence" exhibited by the TADF material refers to light emission having the same spectrum as normal fluorescence and an extremely long lifetime. The lifetime is 1×10^{-6} seconds or longer, preferably 1×10^{-3} seconds or longer.

Examples of the substance that emits phosphorescence are bis{2-[3',5'-bis(trifluoromethyl)phenyl]pyridinato-N,C$^{2'}$}iridium(III) picolinate (abbreviation: [Ir(CF$_3$ppy)$_2$(pic)], bis[2-(4',6'-difluorophenyl)pyridinato-N,C$^{2'}$]iridium(III) acetylacetonate (abbreviation: FIracac), tris(2-phenylpyridinato)iridium(III) (abbreviation: [Ir(ppy)$_3$]), bis(2-phenylpyridinato)iridium(III) acetylacetonate (abbreviation: [Ir(ppy)$_2$(acac)]), tris(acetylacetonato)(monophenanthroline)terbium(III) (abbreviation: [Tb(acac)$_3$(Phen)]), bis(benzo[h]quinolinato)iridium(III) acetylacetonate (abbreviation: [Ir(bzq)$_2$(acac)]), bis(2,4-diphenyl-1,3-oxazolato-N,C$^{2'}$)iridium(III) acetylacetonate (abbreviation: [Ir(dpo)$_2$(acac)]), bis{2-[4'-(perfluorophenyl)phenyl]pyridinato-N,C$^{2'}$}iridium(III) acetylacetonate (abbreviation: [Ir(p-PF-ph)$_2$(acac)]), bis(2-phenylbenzothiazolato-N,C$^{2'}$)iridium(III) acetylacetonate (abbreviation: [Ir(bt)$_2$(acac)]), bis[2-(2'-benzo[4,5-α]thienyl)pyridinato-N,C$^{3'}$]iridium(III) acetylacetonate (abbreviation: [Ir(btp)$_2$(acac)]), bis(1-phenylisoquinolinato-N,C$^{2'}$)iridium(III) acetylacetonate (abbreviation: [Ir(piq)$_2$(acac)]), (acetylacetonato)bis[2,3-bis(4-fluorophenyl)quinoxalinato]iridium(III) (abbreviation: [Ir(Fdpq)$_2$(acac)]), (acetylacetonato)bis(3,5-dimethyl-2-phenylpyrazinato)iridium(III) (abbreviation: [Ir(mppr-Me)$_2$(acac)]), (acetylacetonato)bis(5-isopropyl-3-methyl-2-phenylpyrazinato)iridium(III) (abbreviation: [Ir(mppr-iPr)$_2$(acac)]), (acetylacetonato)bis(2,3,5-triphenylpyrazinato)iridium(III) (abbreviation: [Ir(tppr)$_2$(acac)]), bis(2,3,5-triphenylpyrazinato)(dipivaloylmethanato)iridium(III) (abbreviation: [Ir(tppr)$_2$(dpm)], (acetylacetonato)bis(6-tert-butyl-4-phenylpyrimidinato)iridium(III) (abbreviation: [Ir(tBuppm)$_2$(acac)]), (acetylacetonato)bis(4,6-diphenylpyrimidinato)iridium(III) (abbreviation: [Ir(dppm)$_2$(acac)]), 2,3,7,8,12,13,17,18-octaethyl-21H,23H-porphyrin platinum(II) (abbreviation: PtOEP), tris(1,3-diphenyl-1,3-propanedionato)(monophenanthroline)europium(III) (abbreviation: [Eu(DBM)$_3$(Phen)]), tris[1-(2-thenoyl)-3,3,3-trifluoroacetonato](monophenanthroline)europium(III) (abbreviation: [Eu(TTA)$_3$(Phen)]), and the like.

Examples of the TADF material are fullerene, a derivative thereof, an acridine derivative such as proflavine, eosin, and the like. Other examples are a metal-containing porphyrin, such as a porphyrin containing magnesium (Mg), zinc (Zn), cadmium (Cd), tin (Sn), platinum (Pt), indium (In), or palladium (Pd). Examples of the metal-containing porphyrin are a protoporphyrin-tin fluoride complex (abbreviation: SnF$_2$(Proto IX)), a mesoporphyrin-tin fluoride complex (abbreviation: SnF$_2$(Meso IX)), a hematoporphyrin-tin fluoride complex (abbreviation: SnF$_2$(Hemato IX)), a coproporphyrin tetramethyl ester-tin fluoride complex (abbreviation: SnF$_2$(Copro III-4Me)), an octaethylporphyrin-tin fluoride complex (abbreviation: SnF$_2$(OEP)), an etioporphyrin-tin fluoride complex (abbreviation: SnF$_2$(Etio I)), an octaethylporphyrin-platinum chloride complex (abbreviation: PtCl$_2$OEP), and the like. Alternatively, a heterocyclic compound including a π-electron rich heteroaromatic ring and a π-electron deficient heteroaromatic ring can be used, such as 2-(biphenyl-4-yl)-4,6-bis(12-phenylindolo[2,3-α]carbazol-11-yl)-1,3,5-triazine (abbreviation: PIC-TRZ). Note that a material in which the π-electron rich heteroaromatic ring is directly bonded to the π-electron deficient heteroaromatic ring is particularly preferably used because the donor property of the π-electron rich heteroaromatic ring and the acceptor property of the π-electron deficient heteroaromatic ring are both increased and the energy difference between the S1 level and the T1 level becomes small.

When the light-emitting substance that converts triplet excitation energy into luminescence is used in the light-emitting layer **113**, other than a structure in which one kind of organic compound (host material) is used in addition to the light-emitting substance, the following structure may be employed: a structure where two kinds of organic compounds (the two kinds of organic compounds may include the above host material) that can form an excited complex (also called an exciplex) at the time of recombination of carriers (electrons and holes) in the light-emitting layer **113** are contained in addition to the light-emitting substance. In order to form an excited complex efficiently, it is particularly preferable to combine a compound which easily accepts electrons (a material having an electron-transport property) and a compound which easily accepts holes (a material having a hole-transport property). In the case where the combination of a material having an electron-transport property and a material having a hole-transport property is used as a host material which forms an excited complex as described above, the carrier balance between holes and electrons in the light-emitting layer can be easily optimized by adjustment of the mixture ratio of the material having an electron-transport property and the material having a hole-transport property. The optimization of the carrier balance between holes and electrons in the light-emitting layer can prevent a region in which electrons and holes are recombined from existing on one side in the light-emitting layer. By preventing the region in which electrons and holes are recombined from existing to one side, the reliability of the light-emitting element can be improved.

As the material having an electron-transport property that is preferably used to form the above excited complex, a π-electron deficient heteroaromatic compound such as a nitrogen-containing heteroaromatic compound, a metal complex, or the like can be used. Specific examples include a metal complex such as bis(10-hydroxybenzo[h]quinolinato)beryllium(II) (abbreviation: BeBq$_2$), bis(2-methyl-8-quinolinolato) (4-phenylphenolato)aluminum(III) (abbreviation: BAlq), bis(8-quinolinolato)zinc(II) (abbreviation: Znq), bis[2-(2-benzoxazolyl)phenolato]zinc(II) (abbreviation: ZnPBO), or bis[2-(2-benzothiazolyl)phenolato]zinc(II) (abbreviation: ZnBTZ); a heterocyclic compound having an polyazole skeleton such as 2-(4-biphenylyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole (abbreviation: PBD), 3-(4-biphenylyl)-4-phenyl-5-(4-tert-butylphenyl)-1,2,4-triazole (abbreviation: TAZ), 1,3-bis[5-(p-tert-butylphenyl)-1,3,4-oxadiazol-2-yl]benzene (abbreviation: OXD-7), 9-[4-(5-phenyl-1,3,4-oxadiazol-2-yl)phenyl]-9H-carbazole (abbreviation: CO11), 2,2',2"-(1,3,5-benzenetriyl)tris(1-phenyl-1H-benzimidazole) (abbreviation: TPBI), or 2-[3-(dibenzothiophen-4-yl)phenyl]-1-phenyl-1H-benzimidazole (abbreviation: mDBTBIm-II); a heterocyclic compound having a diazine skeleton such as 2-[3-(dibenzothiophen-4-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 2mDBTPDBq-II), 2-[3'-(dibenzothiophen-4-yl)biphenyl-3-yl]dibenzo[f,h]quinoxaline (abbreviation: 2mDBTBPDBq-II), 2-[3'-(9H-carbazol-9-yl)biphenyl-3-yl]dibenzo[f,h]quinoxaline (abbreviation: 2mCzBPDBq), 2-[4-(3,6-diphenyl-9H-carbazol-9-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 2CzPDBq-III), 7-[3-(dibenzothiophen-4-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 7mDBTPDBq-II); 6-[3-(dibenzothiophen-4-yl)phenyl]dibenzo[f,h]quinoxaline (abbreviation: 6mDBTPDBq-II), 4,6-bis[3-(phenanthren-9-yl)phenyl]pyrimidine (abbreviation: 4,6mPnP2Pm), 4,6-bis[3-(4-dibenzothienyl)phenyl]pyrimidine (abbreviation: 4,6mDBTP2Pm-II), or 4,6-bis[3-(9H-carbazol-9-yl)phenyl]pyrimidine (abbreviation: 4,6mCzP2Pm); a heterocyclic compound having a triazine skeleton such as 2-{4-[3-(N-phenyl-9H-carbazol-3-yl)-9H-carbazol-9-yl]phenyl}-4,6-diphenyl-1,3,5-triazine (abbreviation: PCCzPTzn); and a heterocyclic compound having a pyridine skeleton such as 3,5-bis[3-(9H-carbazol-9-yl)phenyl]pyridine (abbreviation: 35DCzPPy) or 1,3,5-tri[3-(3-pyridyl)phenyl]benzene (abbreviation: TmPyPB). Among the above materials, heterocyclic compounds having diazine skeletons and triazine skeletons and heterocyclic compounds having pyridine skeletons have high reliability and are thus preferable. Heterocyclic compounds having diazine (pyrimidine or pyrazine) skeletons and triazine skeletons have an excellent electron-transport property and contribute to a decrease in drive voltage.

As the compound that is preferably used to form the above excited complex, a π-electron rich heteroaromatic compound (e.g., a carbazole derivative or an indole derivative), an aromatic amine compound, or the like can be favorably used. Specific examples are compounds having aromatic amine skeletons, such as 2-[N-(9-phenylcarbazol-3-yl)-N-phenylamino]spiro-9,9'-bifluorene (abbreviation: PCASF), 4,4',4"-tris[N-(1-naphthyl)-N-phenylamino]triphenylamine (abbreviation: 1'-TNATA), 2,7-bis[N-(4-diphenylaminophenyl)-N-phenylamino]-spiro-9,9'-bifluorene (abbreviation: DPA2SF), N,N'-bis(9-phenylcarbazol-3-yl)-N,N'-diphenylbenzene-1,3-diamine (abbreviation: PCA2B), N-(9,9-dimethyl-2-diphenylamino-9H-fluoren-7-yl)diphenylamine (abbreviation: DPNF), N,N',N"-triphenyl-N,N',N"-tris(9-phenylcarbazol-3-yl)benzene-1,3,5-triamine (abbreviation: PCA3B), 2-[N-(4-diphenylaminophenyl)-N-phenylamino]spiro-9,9'-bifluorene (abbreviation: DPASF), N,N'-bis[4-(carbazol-9-yl)phenyl]-N,N'-diphenyl-9,9-dimethylfluorene-2,7-diamine (abbreviation: YGA2F), NPB, N,N'-bis(3-methylphenyl)-N,N'-diphenyl-[1,1'-biphenyl]-4,4'-diamine (abbreviation: TPD), 4,4'-bis[N-(4-diphenylaminophenyl)-N-phenylamino]biphenyl (abbreviation: DPAB), BSPB, 4-phenyl-4'-(9-phenylfluoren-9-yl)triphenylamine (abbreviation: BPAFLP), 4-phenyl-3'-(9-phenylfluoren-9-yl)triphenylamine (abbreviation: mBPAFLP), N-(9,9-dimethyl-9H-fluoren-2-yl)-N-{9,9-dimethyl-2-[N'-phenyl-N'-(9,9-dimethyl-9H-fluoren-2-yl)amino]-9H-fluoren-7-yl}phenylamine (abbreviation: DFLADFL), PCzPCA1, 3-[N-(4-diphenylaminophenyl)-N-phenylamino]-9-phenyl carbazole (abbreviation: PCzDPA1), 3,6-bis[N-(4-diphenylaminophenyl)-N-phenylamino]-9-phenylcarbazole (abbreviation: PCzDPA2), DNTPD, 3,6-bis[N-(4-diphenylaminophenyl)-N-(1-naphthyl)amino]-9-phenylcarbazole (abbreviation: PCzTPN2), PCzPCA2, 4-phenyl-4'-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBA1BP), 4,4'-diphenyl-4"-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBBi1BP), 4-(1-naphthyl)-4'-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBANB), 4,4'-di(1-naphthyl)-4"-(9-phenyl-9H-carbazol-3-yl)triphenylamine (abbreviation: PCBNBB), 3-[N-(1-naphthyl)-N-(9-phenylcarbazol-3-yl)amino]-9-phenylcarbazole (abbreviation: PCzPCN1), 9,9-dimethyl-N-phenyl-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]fluoren-2-amine (abbreviation: PCBAF), N-phenyl-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]spiro-9,9'-bifluoren-2-amine (abbreviation: PCBASF), N-(4-biphenyl)-N-(9,9-dimethyl-9H-fluoren-2-yl)-9-phenyl-9H-carbazol-3-amine (abbreviation: PCBiF), and N-(1,1'-biphenyl-4-yl)-N-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]-9,9-dimethyl-9H-fluoren-2-amine (abbreviation: PCBBiF); compounds having carbazole skeletons, such as 1,3-bis(N-carbazolyl)benzene (abbreviation: mCP), CBP, 3,6-bis(3,5-diphenylphenyl)-9-phenylcarbazole (abbreviation: CzTP), and 9-phenyl-9H-3-(9-phenyl-9H-carbazol-3-yl)carbazole (abbreviation: PCCP); compounds having thiophene skeletons, such as 4,4',4"-(benzene-1,3,5-triyl)tri(dibenzothiophene) (abbreviation: DBT3P-II), 2,8-diphenyl-4-[4-(9-phenyl-9H-fluoren-9-yl)phenyl]dibenzothiophene (abbreviation: DBTFLP-III), and 4-[4-(9-phenyl-9H-fluoren-9-yl)phenyl]-6-phenyldibenzothiophene (abbreviation: DBTFLP-IV); and compounds having furan skeletons, such as 4,4',4"-(benzene-1,3,5-triyl)tri(dibenzofuran) (abbreviation: DBF3P-II) and 4-{3-[3-(9-phenyl-9H-fluoren-9-yl)phenyl]phenyl}dibenzofuran (abbreviation: mmDBFFLBi-II). Among the above materials, the compounds having aromatic amine skeletons and the compounds having carbazole skeletons are preferred because these compounds are highly reliable and have an excellent hole-transport property and contribute to a reduction in drive voltage.

In the light-emitting element, the light-emitting layer **113** does not necessarily have the single-layer structure illustrated in FIG. **4**A and may have a stacked-layer structure including two or more layers as illustrated in FIG. **4**B. In that case, each layer in the stacked-layer structure emits light. For example, fluorescence utilizing TTA is obtained from a first light-emitting layer **113**(*a***1**), and phosphorescence is obtained from a second light-emitting layer **113**(*a***2**) stacked over the first light-emitting layer. Note that the stacking order may be reversed. It is preferable that light emission due to energy transfer from an excited complex to a dopant be obtained from the layer that emits phosphorescence. The emission color of one layer and that of the other layer may be the same or different. In the case where the emission colors are different, a structure in which, for example, blue light from one layer and orange, yellow light, or the like from the other layer can be obtained can be formed. Each layer may contain various kinds of dopants.

Note that in the case where the light-emitting layer **113** has a stacked-layer structure, a light-emitting substance converting singlet excitation energy into light emission or a light-emitting substance converting triplet excitation energy into light emission can be used alone or in combination, for example. In that case, the following substances can be used.

The electron-transport layer **114** is a layer containing a substance having a high electron-transport property (also referred to as an electron-transport compound). For the electron-transport layer **114**, a metal complex such as tris(8-quinolinolato)aluminum (abbreviation: Alq_3), tris(4-methyl-8-quinolinolato)aluminum (abbreviation: $Almq_3$), $BeBq_2$, BAlq, bis[2-(2-hydroxyphenyl)benzoxazolato]zinc (abbreviation: $Zn(BOX)_2$), or bis[2-(2-hydroxyphenyl)benzothiazolato]zinc (abbreviation: $Zn(BTZ)_2$) can be used. Alternatively, a heteroaromatic compound such as PBD, TAZ, 3-(4-tert-butylphenyl)-4-(4-ethylphenyl)-5-(4-biphenylyl)-1,2,4-triazole (abbreviation: p-EtTAZ), bathophenanthroline (abbreviation: Bphen), bathocuproine (abbreviation: BCP), or 4,4'-bis(5-methylbenzoxazol-2-yl)stilbene (abbreviation: BzOs) can also be used. A high molecular compound such as poly(2,5-pyridinediyl) (abbreviation: PPy), poly[(9,9-dihexylfluorene-2,7-diyl)-co-(pyridine-3,5-diyl)] (abbreviation: PF-Py), or poly[(9,9-dioctylfluorene-2,7-diyl)-co-(2,2'-bipyridine-6,6'-diyl)] (abbreviation: PF-BPy) can also be used. The substances listed here are mainly ones that have an electron mobility of 1×10^{-6} cm^2/Vs or more. Note that any substance other than the substances listed here may be used for the electron-transport layer **114** as long as the electron-transport property is higher than the hole-transport property.

The substance used for the electron-transport layer **114** preferably has higher S_1 and T_1 levels than the light-emitting layer **113** that is adjacent to the electron-transport layer **114** because diffusion of excitation energy to the electron-transport layer **114** can be prevented. Furthermore, the substance used for the electron-transport layer **114** preferably has a deeper HOMO level (a smaller value) than the light-emitting layer **113** adjacent to the electron-transport layer **114** because passage of holes through the light-emitting layer **113** to the electron-transport layer **114** can be suppressed. Furthermore, a LUMO level of the substance used for the electron-transport layer **114** is preferably higher (a larger value) than or substantially equal to the LUMO level of the light-emitting layer **113** that is adjacent to the electron-transport layer **114** because easier electron-injection into the light-emitting layer **113** can be achieved.

The electron-transport layer **114** is not limited to a single layer, but may be a stack of two or more layers each containing any of the substances listed above.

The electron-injection layer **115** is a layer containing a substance having a high electron-injection property. For the electron-injection layer **115**, an alkali metal, an alkaline earth metal, or a compound thereof such as lithium fluoride (LiF), cesium fluoride (CsF), calcium fluoride (CaF_2), or lithium oxide (LiO_x) can be used. A rare earth metal compound like erbium fluoride (ErF_3) can also be used. An electride may also be used for the electron-injection layer **115**. Examples of the electride include a substance in which electrons are added at high concentration to calcium oxide-aluminum oxide. Any of the substances for forming the electron-transport layer **114**, which are given above, can be used.

A composite material in which an organic compound and an electron donor (donor) are mixed may also be used for the electron-injection layer **115**. Such a composite material is excellent in an electron-injection property and an electron-transport property because electrons are generated in the organic compound by the electron donor. In this case, the organic compound is preferably a material that is excellent in transporting the generated electrons. Specifically, for example, the substances for forming the electron-transport layer **114** (e.g., a metal complex or a heteroaromatic compound), which are given above, can be used. As the electron donor, a substance showing an electron-donating property with respect to the organic compound may be used. Specifically, an alkali metal, an alkaline earth metal, and a rare earth metal are preferable, and lithium, cesium, magnesium, calcium, erbium, ytterbium, and the like are given. In addition, an alkali metal oxide or an alkaline earth metal oxide is preferable, and lithium oxide, calcium oxide, barium oxide, and the like are given. A Lewis base such as magnesium oxide can also be used. An organic compound such as tetrathiafulvalene (abbreviation: TTF) can also be used.

Note that each of the hole-injection layer **111**, the hole-transport layer **112**, the light-emitting layer **113**, the electron-transport layer **114**, and the electron-injection layer **115** can be formed by any one or any combination of the following methods: an evaporation method (including a vacuum evaporation method), a printing method (such as relief printing, intaglio printing, gravure printing, planography printing, and stencil printing), an ink-jet method, a coating method, and the like. Besides the above-mentioned materials, an inorganic compound such as a quantum dot or a high molecular compound (e.g., an oligomer, a dendrimer, or a polymer) may be used for the hole-injection layer **111**, the hole-transport layer **112**, the light-emitting layer **113**, the electron-transport layer **114**, and the electron-injection layer **115**, which are described above.

In the above light-emitting element, current flows due to a potential difference applied between the first electrode **101** and the second electrode **103** and holes and electrons recombine in the EL layer **102**, whereby light is emitted. Then, the emitted light is extracted outside through one or both of the first electrode **101** and the second electrode **103**. Therefore, one or both of the first electrode **101** and the second electrode **103** are electrodes having a light-transmitting property.

As described above, in the light-emitting element of this embodiment, the characteristics of the light-emitting element can be improved by the use of the above-described desired structure for a light-emitting layer. Specifically, when TTA is utilized, light efficiency due to singlet excitation energy can be improved, whereby the light-emitting element can have higher efficiency than a conventional fluorescent light-emitting element.

Note that the structure described in this embodiment can be used in combination with any of the structures described in the other embodiments, as appropriate.

Embodiment 4

In this embodiment, a light-emitting element (hereinafter referred to as a tandem light-emitting element) including a plurality of EL layers is described.

A light-emitting element described in this embodiment is a tandem light-emitting element including, between a pair of electrodes (a first electrode **201** and a second electrode **204**), a plurality of EL layers (a first EL layer **202(1)** and a second EL layer **202(2)**) and a charge-generation layer **205** provided therebetween, as illustrated in FIG. **5A**.

In this embodiment, the first electrode **201** functions as an anode, and the second electrode **204** functions as a cathode. Note that the first electrode **201** and the second electrode **204** can have structures similar to those described in Embodiment 3. In addition, either or both of the EL layers (the first EL layer **202(1)** and the second EL layer **202(2)**) may have structures similar to those described in Embodiment 3. In other words, the structures of the first EL layer **202(1)** and the second EL layer **202**(**2**) may be the same as or different from each other. When the structures are the same, Embodiment 3 can be referred to.

The charge-generation layer **205** provided between the plurality of EL layers (the first EL layer **202**(**1**) and the second EL layer **202**(**2**)) has a function of injecting electrons into one of the EL layers and injecting holes into the other of the EL layers when a voltage is applied between the first electrode **201** and the second electrode **204**. In this embodiment, when a voltage is applied such that the potential of the first electrode **201** is higher than that of the second electrode **204**, the charge-generation layer **205** injects electrons into the first EL layer **202**(**1**) and injects holes into the second EL layer **202**(**2**).

Note that in terms of light extraction efficiency, the charge-generation layer **205** preferably has a property of transmitting visible light (specifically, the charge-generation layer **205** has a visible light transmittance of 40% or more). The charge-generation layer **205** functions even when it has lower conductivity than the first electrode **201** or the second electrode **204**.

The charge-generation layer **205** may have either a structure in which an electron acceptor (acceptor) is added to an organic compound having a high hole-transport property or a structure in which an electron donor (donor) is added to an organic compound having a high electron-transport property. Alternatively, both of these structures may be stacked.

In the case of the structure in which an electron acceptor is added to an organic compound having a high hole-transport property, as the organic compound having a high hole-transport property, the substances having a high hole-transport property which are given in Embodiment 3 as the substances used for the hole-injection layer **111** and the hole-transport layer **112** can be used. For example, an aromatic amine compound such as NPB, TPD, TDATA, MTDATA, or BSPB, or the like can be used. The substances listed here are mainly ones that have a hole mobility of 1×10^{-6} cm^2/Vs or more. Note that any organic compound other than the compounds listed here may be used as long as the hole-transport property is higher than the electron-transport property.

As the electron acceptor, 7,7,8,8-tetracyano-2,3,5,6-tetrafluoroquinodimethane (abbreviation: F_4-TCNQ), chloranil, and the like can be given. Oxides of metals belonging to Groups 4 to 8 of the periodic table can also be given. Specifically, vanadium oxide, niobium oxide, tantalum oxide, chromium oxide, molybdenum oxide, tungsten oxide, manganese oxide, and rhenium oxide are preferable because of their high electron-accepting properties. Among these, molybdenum oxide is especially preferable because it is stable in the air, has a low hygroscopic property, and is easy to handle.

In the case of the structure in which an electron donor is added to an organic compound having a high electron-transport property, as the organic compound having a high electron-transport property, the substances having a high electron-transport property which are given in Embodiment 3 as the substances used for the electron-transport layer **114** can be used. For example, a metal complex having a quinoline skeleton or a benzoquinoline skeleton, such as Alq, $Almq_3$, $BeBq_2$, or BAlq, or the like can be used. Alternatively, a metal complex having an oxazole-based ligand or a thiazole-based ligand, such as $Zn(BOX)_2$ or $Zn(BTZ)_2$, can be used. Alternatively, in addition to such a metal complex, PBD, OXD-7, TAZ, Bphen, BCP, or the like can be used. The substances listed here are mainly ones that have an electron mobility of 1×10^{-6} cm^2/Vs or more. Note that any organic compound other than the compounds listed here may be used as long as the electron-transport property is higher than the hole-transport property.

As the electron donor, it is possible to use an alkali metal, an alkaline earth metal, a rare earth metal, metals belonging to Groups 2 and 13 of the periodic table, or an oxide or carbonate thereof. Specifically, lithium (Li), cesium (Cs), magnesium (Mg), calcium (Ca), ytterbium (Yb), indium (In), lithium oxide, cesium carbonate, or the like is preferably used. Alternatively, an organic compound such as tetrathianaphthacene may be used as the electron donor.

Note that forming the charge-generation layer **205** by using any of the above materials can suppress a drive voltage increase caused by the stack of the EL layers. The charge-generation layer **205** can be formed by any one or any combination of the following methods: an evaporation method (including a vacuum evaporation method), a printing method (such as relief printing, intaglio printing, gravure printing, planography printing, and stencil printing), an ink-jet method, a coating method, and the like.

Although the light-emitting element including two EL layers is described in this embodiment, the present invention can be similarly applied to a light-emitting element in which n EL layers (**202**(**1**) to **202**(*n*)) (n is three or more) are stacked as illustrated in FIG. **5**B. In the case where a plurality of EL layers are included between a pair of electrodes as in the light-emitting element according to this embodiment, by providing charge-generation layers (**205**(**1**) to **205**(*n*−1)) between the EL layers, light emission in a high luminance region can be obtained with current density kept low. Since the current density can be kept low, the element can have a long lifetime.

When the EL layers have different emission colors, a desired emission color can be obtained from the whole light-emitting element. For example, in a light-emitting element having two EL layers, when an emission color of the first EL layer and an emission color of the second EL layer are complementary colors, the light-emitting element can emit white light as a whole. Note that "complementary colors" refer to colors that can produce an achromatic color when mixed. In other words, mixing light of complementary colors allows white light emission to be obtained. Specifically, a combination in which blue light emission is obtained from the first EL layer and yellow or orange light emission is obtained from the second EL layer is given as an example. In that case, it is not necessary that both of blue light emission and yellow (or orange) light emission are fluorescence, and the both are not necessarily phosphorescence. For example, a combination in which blue light emission is fluorescence and yellow (or orange) light emission is phosphorescence or a combination in which blue light emission is phosphorescence and yellow (or orange) light emission is fluorescence may be employed.

The same can be applied to a light-emitting element having three EL layers. For example, the light-emitting element as a whole can provide white light emission when the emission color of the first EL layer is red, the emission color of the second EL layer is green, and the emission color of the third EL layer is blue.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 5

In this embodiment, a light-emitting device will be described.

The light-emitting device may be either a passive matrix light-emitting device or an active matrix light-emitting device. Any of the light-emitting elements described in other embodiments can be used in the light-emitting device described in this embodiment.

In this embodiment, first, an active matrix light-emitting device is described with reference to FIGS. **6**A to **6**C.

Note that FIG. **6**A is a top view illustrating a light-emitting device and FIG. **6**B is a cross-sectional view taken along the chain line A-A' in FIG. **6**A. The light-emitting device of this embodiment includes a pixel portion **302** provided over an element substrate **301**, a driver circuit portion (a source line driver circuit) **303**, and driver circuit portions (gate line driver circuits) **304***a* and **304***b*. The pixel portion **302**, the driver circuit portion **303**, and the driver circuit portions **304***a* and **304***b* are sealed between the element substrate **301** and a sealing substrate **306** with a sealant **305**.

In addition, over the element substrate **301**, a lead wiring **307** for connecting an external input terminal, through which a signal (e.g., a video signal, a clock signal, a start signal, or a reset signal) or an potential from the outside is transmitted to the driver circuit portion **303** and the driver circuit portions **304***a* and **304***b*, is provided. Here, an example is described in which a flexible printed circuit (FPC) **308** is provided as the external input terminal. Although only the FPC is illustrated here, the FPC may be provided with a printed wiring board (PWB). The light-emitting device in this specification includes, in its category, not only the light-emitting device itself but also the light-emitting device provided with the FPC or the PWB.

Next, a cross-sectional structure is described with reference to FIG. **6**B. The driver circuit portions and the pixel portion are formed over the element substrate **301**; the driver circuit portion **303** that is the source line driver circuit and the pixel portion **302** are illustrated here.

The driver circuit portion **303** is an example in which FETs **309** and **310** are combined. Note that the driver circuit portion **303** may be formed with a circuit including transistors having the same conductivity type (either n-channel transistors or p-channel transistors) or a CMOS circuit including an n-channel transistor and a p-channel transistor. Although this embodiment shows a driver integrated type in which the driver circuit is formed over the substrate, the driver circuit is not necessarily formed over the substrate, and may be formed outside the substrate.

The pixel portion **302** includes a switching FET (not illustrated) and a current control FET **312**, and a wiring of the current control FET **312** (a source electrode or a drain electrode) is electrically connected to a first electrode (anode) (**313***a* or **313***b*) of a light-emitting element **317***a* or **317***b*. Although the pixel portion **302** includes two kinds of FETs (the switching FET and the current control FETs **312**) in this embodiment, one embodiment of the present invention is not limited thereto. The pixel portion **302** may include, for example, three or more kinds of FETs and a capacitor in combination.

As the FETs **309**, **310**, and **312**, for example, a staggered transistor or an inverted staggered transistor can be used. Examples of a semiconductor material that can be used for the FETs **309**, **310**, and **312** are a Group 13 semiconductor, a Group 14 semiconductor (e.g., silicon), a compound semiconductor, an oxide semiconductor, and an organic semiconductor. In addition, there is no particular limitation on the crystallinity of the semiconductor material, and an amorphous semiconductor or a crystalline semiconductor can be used. In particular, an oxide semiconductor is preferably used for the FETs **309**, **310**, and **312**. Examples of the oxide semiconductor are In—Ga oxides, In-M-Zn oxides (M is Al, Ga, Y, Zr, La, Ce, Hf, or Nd), and the like. For example, an oxide semiconductor material that has an energy gap of 2 eV or more, preferably 2.5 eV or more and further preferably 3 eV or more, is used, so that the off-state current of the transistors can be reduced.

In addition, conductive films (**320***a* and **320***b*) for optical adjustment are stacked over the first electrodes **313***a* and **313***b*. For example, as illustrated in FIG. **6**B, in the case where the wavelengths of light extracted from the light-emitting elements **317***a* and **317***b* are different from each other, the thicknesses of the conductive films **320***a* and **320***b* are different from each other. In addition, an insulator **314** is formed to cover end portions of the first electrodes (**313***a* and **313***b*). In this embodiment, the insulator **314** is formed using a positive photosensitive acrylic resin. The first electrodes (**313***a* and **313***b*) are used as the anodes in this embodiment.

The insulator **314** preferably has a curved surface with curvature at an upper end portion or a lower end portion thereof. This enables favorable coverage by a film to be formed over the insulator **314**. The insulator **314** can be formed using, for example, either a negative photosensitive resin or a positive photosensitive resin. The material for the insulator **314** is not limited to an organic compound and an inorganic compound such as silicon oxide, silicon oxynitride, or silicon nitride can also be used.

An EL layer **315** and a second electrode **316** are stacked over the first electrodes (**313***a* and **313***b*). In the EL layer **315**, at least a light-emitting layer is provided. In the light-emitting elements (**317***a* and **317***b*) including the first electrodes (**313***a* and **313***b*), the EL layer **315**, and the second electrode **316**, an end portion of the EL layer **315** is covered with the second electrode **316**. The structure of the EL layer **315** may be the same as or different from the single-layer structure and the stacked layer structure described in Embodiments 2 and 3. Furthermore, the structure may differ between the light-emitting elements.

For the first electrode **313**, the EL layer **315**, and the second electrode **316**, any of the materials given in Embodiment 3 can be used. The first electrodes (**313***a* and **313***b*) of the light-emitting elements (**317***a* and **317***b*) are electrically connected to the lead wiring **307** in a region **321**, so that an external signal is input through the FPC **308**. The second electrode **316** of the light-emitting elements (**317***a* and **317***b*) is electrically connected to a lead wiring **323** in a region **322**, so that an external signal is input through the FPC **308** although it is not illustrated.

Although the cross-sectional view in FIG. **6**B illustrates only the two light-emitting elements **317**, a plurality of light-emitting elements are arranged in a matrix in the pixel portion **302**. Specifically, in the pixel portion **302**, light-emitting elements that emit light of two kinds of colors (e.g., B and Y), light-emitting elements that emit light of three kinds of colors (e.g., R, G, and B), light-emitting elements that emit light of four kinds of colors (e.g. R, G, B, and Y) or (R, G, B, and W)), or the like are formed so that a light-emitting device capable of full color display can be obtained. In such cases, full color display may be achieved as follows: materials different according to the emission colors or the like of the light-emitting elements are used to form light-emitting layers (so-called separate coloring formation); alternatively, the plurality of light-emitting elements share one light-emitting layer formed using the same material and further include color filters. Thus, the light-emitting elements that emit light of a plurality of kinds of colors are used in combination, so that effects such as an improvement in color purity and a reduction in power consumption can be achieved. Furthermore, the light-emitting device may have improved emission efficiency and reduced power consumption by combination with quantum dots.

The sealing substrate **306** is attached to the element substrate **301** with the sealant **305**, whereby the light-emitting elements **317***a* and **317***b* are provided in a space **318** surrounded by the element substrate **301**, the sealing substrate **306**, and the sealant **305**.

The sealing substrate **306** is provided with coloring layers (color filters) **324**, and a black layer (black matrix) **325** is provided between adjacent coloring layers. Note that one or both of the adjacent coloring layers (color filters) **324** may be provided so as to partly overlap with the black layer (black matrix) **325**. Light emission obtained from the light-emitting elements **317***a* and **317***b* is extracted through the coloring layers (color filters) **324**.

Note that the space **318** may be filled with an inert gas (such as nitrogen or argon) or the sealant **305**. In the case where the sealant is applied for attachment of the substrates, one or more of UV treatment, heat treatment, and the like are preferably performed.

An epoxy-based resin or glass frit is preferably used for the sealant **305**. The material preferably allows as little moisture and oxygen as possible to penetrate. As the sealing substrate **306**, a glass substrate, a quartz substrate, or a plastic substrate formed of fiber-reinforced plastic (FRP), poly(vinyl fluoride) (PVF), polyester, acrylic, or the like can be used. In the case where glass frit is used as the sealant, the element substrate **301** and the sealing substrate **306** are preferably glass substrates for high adhesion.

Structures of the FETs electrically connected to the light-emitting elements may be different from those in FIG. **6**B in the position of a gate electrode; that is, the structures of FETs **326**, **327**, and **328** as illustrated in FIG. **6**C may be employed. The coloring layer (color filter) **324** with which the sealing substrate **306** is provided may be provided as illustrated in FIG. **6**C such that, at a position where the coloring layer (color filter) **324** overlaps with the black layer (black matrix) **325**, the coloring layer (color filter) **324** further overlaps with an adjacent coloring layer (color filter) **324**.

As described above, an active matrix light-emitting device can be obtained.

Note that the light-emitting device can be a passive matrix light-emitting device as well as the above active matrix light-emitting device.

FIGS. **7**A and **7**B illustrate a passive-matrix light-emitting device. FIG. **7**A is a top view of the passive-matrix light-emitting device, and FIG. **7**B is a cross-sectional view thereof.

As illustrated in FIGS. **7**A and **7**B, light-emitting elements **405** including a first electrode **402**, EL layers (**403***a*, **403***b*, and **403***c*), and second electrodes **404** are formed over a substrate **401**. Note that the first electrode **402** has an island-like shape, and a plurality of the first electrodes **402** are formed in one direction (the lateral direction in FIG. **7**A) to form a striped pattern. An insulating film **406** is formed over part of the first electrode **402**. A partition **407** formed using an insulating material is provided over the insulating film **406**. The sidewalls of the partition **407** slope so that the distance between one sidewall and the other sidewall gradually decreases toward the surface of the substrate as illustrated in FIG. **7**B.

Since the insulating film **406** has openings in part of the first electrode **402**, the EL layers (**403***a*, **403***b*, and **403***c*) and second electrodes **404** which are divided as desired can be formed over the first electrode **402**. In the example in FIGS. **7**A and **7**B, a mask such as a metal mask and the partition **407** over the insulating film **406** are employed to form the EL layers (**403***a*, **403***b*, and **403***c*) and the second electrodes **404**. In this example, the EL layers **403***a*, **403***b*, and **403***c* emit light of different colors (e.g., red, green, blue, yellow, orange, and white).

After the formation of the EL layers (**403***a*, **403***b*, and **403***c*), the second electrodes **404** are formed. Thus, the second electrode **404** is formed over the EL layers (**403***a*, **403***b*, and **403***c*) without contact with the first electrode **402**.

Note that sealing can be performed by a method similar to that used for the active matrix light-emitting device, and description thereof is not made.

As described above, the passive matrix light-emitting device can be obtained.

Note that in this specification and the like, a transistor or a light-emitting element can be formed using any of a variety of substrates, for example. The type of a substrate is not limited to a certain type. As the substrate, a semiconductor substrate (e.g., a single crystal substrate or a silicon substrate), an SOI substrate, a glass substrate, a quartz substrate, a plastic substrate, a metal substrate, a stainless steel substrate, a substrate including stainless steel foil, a tungsten substrate, a substrate including tungsten foil, a flexible substrate, an attachment film, paper including a fibrous material, a base material film, or the like can be used, for example. As an example of a glass substrate, a barium borosilicate glass substrate, an aluminoborosilicate glass substrate, a soda lime glass substrate, or the like can be given. Examples of the flexible substrate, the attachment film, the base film, and the like are substrates of plastics typified by polyethylene terephthalate (PET), polyethylene naphthalate (PEN), polyether sulfone (PES), and polytetrafluoroethylene (PTFE). Another example is a synthetic resin such as acrylic. Alternatively, polypropylene, polyester, polyvinyl fluoride, polyvinyl chloride, or the like can be used. Alternatively, polyamide, polyimide, aramid, epoxy, an inorganic vapor deposition film, paper, or the like can be used. Specifically, the use of semiconductor substrates, single crystal substrates, SOI substrates, or the like enables the manufacture of small-sized transistors with a small variation in characteristics, size, shape, or the like and with high current supply capability. A circuit using such transistors achieves low power consumption of the circuit or high integration of the circuit.

Alternatively, a flexible substrate may be used as the substrate, and a transistor or a light-emitting element may be provided directly on the flexible substrate. Still alternatively, a separation layer may be provided between the substrate and the transistor or the light-emitting element. The separation layer can be used when part or the whole of a semiconductor device formed over the separation layer is separated from the substrate and transferred onto another substrate. In such a case, the transistor or the light-emitting element can be transferred to a substrate having low heat resistance or a flexible substrate. For the separation layer, a stack including inorganic films, which are a tungsten film and a silicon oxide film, or an organic resin film of polyimide or the like formed over a substrate can be used, for example.

In other words, a transistor or a light-emitting element may be formed using one substrate, and then transferred to another substrate. Examples of a substrate to which a transistor or a light-emitting element is transferred are, in addition to the above-described substrates over which a transistor or a light-emitting element can be formed, a paper substrate, a cellophane substrate, an aramid film substrate, a polyimide film substrate, a stone substrate, a wood substrate, a cloth substrate (including a natural fiber (e.g., silk, cotton, or hemp), a synthetic fiber (e.g., nylon, polyurethane, or polyester), a regenerated fiber (e.g., acetate, cupra, rayon, or regenerated polyester), or the like), a leather substrate, a rubber substrate, and the like. When such a substrate is used, a transistor with excellent characteristics or a transistor with low power consumption can be formed, a device with high durability or high heat resistance can be provided, or a reduction in weight or thickness can be achieved.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 6

In this embodiment, examples of a variety of electronic devices and an automobile manufactured using a light-emitting device which is one embodiment of the present invention are described.

Examples of the electronic device including the light-emitting device are television devices (also referred to as TV or television receivers), monitors for computers and the like, digital cameras, digital video cameras, digital photo frames, cellular phones (also referred to as portable telephone devices), portable game consoles, portable information terminals, audio playback devices, large game machines such as pachinko machines, and the like. Specific examples of the electronic devices are illustrated in FIGS. **8**A, **8**B, **8**C, **8**D, **8**D'-**1**, and **8**D'-**2**, and FIGS. **9**A to **9**C.

FIG. **8**A illustrates an example of a television device. In the television device **7100**, a display portion **7103** is incorporated in a housing **7101**. The display portion **7103** can display images and may be a touch panel (an input/output device) including a touch sensor (an input device). Note that the light-emitting device which is one embodiment of the present invention can be used for the display portion **7103**. In addition, here, the housing **7101** is supported by a stand **7105**.

The television device **7100** can be operated by an operation switch of the housing **7101** or a separate remote controller **7110**. With operation keys **7109** of the remote controller **7110**, channels and volume can be controlled and images displayed on the display portion **7103** can be controlled. Furthermore, the remote controller **7110** may be provided with a display portion **7107** for displaying data output from the remote controller **7110**.

Note that the television device **7100** is provided with a receiver, a modem, and the like. With the use of the receiver, general television broadcasts can be received. Moreover, when the television device is connected to a communication network with or without wires via the modem, one-way (from a sender to a receiver) or two-way (between a sender and a receiver or between receivers) information communication can be performed.

FIG. **8**B illustrates a computer, which includes a main body **7201**, a housing **7202**, a display portion **7203**, a keyboard **7204**, an external connection port **7205**, a pointing device **7206**, and the like. Note that this computer can be manufactured using the light-emitting device which is one embodiment of the present invention for the display portion **7203**. The display portion **7203** may be a touch panel (an input/output device) including a touch sensor (an input device).

FIG. **8**C illustrates a smart watch, which includes a housing **7302**, a display portion **7304**, operation buttons **7311** and **7312**, a connection terminal **7313**, a band **7321**, a clasp **7322**, and the like.

The display portion **7304** mounted in the housing **7302** serving as a bezel includes a non-rectangular display region. The display portion **7304** can display an icon **7305** indicating time, another icon **7306**, and the like. The display portion **7304** may be a touch panel (an input/output device) including a touch sensor (an input device).

The smart watch illustrated in FIG. **8**C can have a variety of functions, such as a function of displaying a variety of information (e.g., a still image, a moving image, and a text image) on a display portion, a touch panel function, a function of displaying a calendar, date, time, and the like, a function of controlling processing with a variety of software (programs), a wireless communication function, a function of being connected to a variety of computer networks with a wireless communication function, a function of transmitting and receiving a variety of data with a wireless communication function, and a function of reading program or data stored in a recording medium and displaying the program or data on a display portion.

The housing **7302** can include a speaker, a sensor (a sensor having a function of measuring force, displacement, position, speed, acceleration, angular velocity, rotational frequency, distance, light, liquid, magnetism, temperature, chemical substance, sound, time, hardness, electric field, current, voltage, electric power, radiation, flow rate, humidity, gradient, oscillation, odor, or infrared rays), a microphone, and the like. Note that the smart watch can be manufactured using the light-emitting device for the display portion **7304**.

FIGS. **8**D, **8**D'-**1**, and **8**D'-**2** illustrate an example of a cellular phone (e.g., smartphone). A cellular phone **7400** includes a housing **7401** provided with a display portion **7402**, a microphone **7406**, a speaker **7405**, a camera **7407**, an external connection portion **7404**, an operation button **7403**, and the like. In the case where a light-emitting device is manufactured by forming a light-emitting element of one embodiment of the present invention over a flexible substrate, the light-emitting element can be used for the display portion **7402** having a curved surface as illustrated in FIG. **8**D.

When the display portion **7402** of the cellular phone **7400** illustrated in FIG. **8**D is touched with a finger or the like, data can be input to the cellular phone **7400**. In addition, operations such as making a call and composing e-mail can be performed by touch on the display portion **7402** with a finger or the like.

There are mainly three screen modes of the display portion **7402**. The first mode is a display mode mainly for displaying an image. The second mode is an input mode mainly for inputting data such as characters. The third mode is a display-and-input mode in which two modes of the display mode and the input mode are combined.

For example, in the case of making a call or creating e-mail, a character input mode mainly for inputting characters is selected for the display portion **7402** so that characters displayed on the screen can be input. In this case, it is preferable to display a keyboard or number buttons on almost the entire screen of the display portion **7402**.

When a detection device such as a gyroscope or an acceleration sensor is provided inside the cellular phone **7400**, display on the screen of the display portion **7402** can be automatically changed by determining the orientation of the cellular phone **7400** (whether the cellular phone is placed horizontally or vertically for a landscape mode or a portrait mode).

The screen modes are changed by touch on the display portion **7402** or operation with the operation button **7403** of the housing **7401**. The screen modes can be switched depending on the kind of images displayed on the display portion **7402**. For example, when a signal of an image displayed on the display portion is a signal of moving image data, the screen mode is switched to the display mode. When the signal is a signal of text data, the screen mode is switched to the input mode.

Moreover, in the input mode, if a signal detected by an optical sensor in the display portion **7402** is detected and the input by touch on the display portion **7402** is not performed for a certain period, the screen mode may be controlled so as to be changed from the input mode to the display mode.

The display portion **7402** may function as an image sensor. For example, an image of a palm print, a fingerprint, or the like is taken by touch on the display portion **7402** with the palm or the finger, whereby personal authentication can be performed. In addition, by providing a backlight or a sensing light source that emits near-infrared light in the display portion, an image of a finger vein, a palm vein, or the like can be taken.

The light-emitting device can be used for a cellular phone having a structure illustrated in FIG. **8**D'-**1** or FIG. **8**D'-**2**, which is another structure of the cellular phone (e.g., a smartphone).

Note that in the case of the structure illustrated in FIG. **8**D'-**1** or FIG. **8**D'-**2**, text data, image data, or the like can be displayed on second screens **7502**(**1**) and **7502**(**2**) of housings **75000**) and **7500**(**2**) as well as first screens **7501**(**1**) and **7501**(**2**). Such a structure enables a user to easily see text data, image data, or the like displayed on the second screens **7502**(**1**) and **7502**(**2**) while the cellular phone is placed in user's breast pocket.

Another electronic device including a light-emitting device is a foldable portable information terminal illustrated in FIGS. **9**A to **9**C. FIG. **9**A illustrates a portable information terminal **9310** which is opened. FIG. **9**B illustrates the portable information terminal **9310** which is being opened or being folded. FIG. **9**C illustrates the portable information terminal **9310** that is folded. The portable information terminal **9310** is highly portable when folded. The portable information terminal **9310** is highly browsable when opened because of a seamless large display region.

A display portion **9311** is supported by three housings **9315** joined together by hinges **9313**. Note that the display portion **9311** may be a touch panel (an input/output device) including a touch sensor (an input device). By bending the display portion **9311** at a connection portion between two housings **9315** with the use of the hinges **9313**, the portable information terminal **9310** can be reversibly changed in shape from an opened state to a folded state. A light-emitting device of one embodiment of the present invention can be used for the display portion **9311**. A display region **9312** in the display portion **9311** is a display region that is positioned at a side surface of the portable information terminal **9310** that is folded. On the display region **9312**, information icons, file shortcuts of frequently used applications or programs, and the like can be displayed, and confirmation of information and start of application can be smoothly performed.

FIGS. **10**A and **10**B illustrate an automobile including a light-emitting device. The light-emitting device can be incorporated in the automobile, and specifically, can be included in lights **5101** (including lights of the rear part of the car), a wheel **5102** of a tire, part or whole of a door **5103**, or the like on the outer side of the automobile which is illustrated in FIG. **10**A. The light-emitting device can also be included in a display portion **5104**, a steering wheel **5105**, a gear lever **5106**, a seat **5107**, an inner rearview mirror **5108**, or the like on the inner side of the automobile which is illustrated in FIG. **10**B, or in part of a glass window.

As described above, the electronic devices and automobiles can be obtained using the light-emitting device which is one embodiment of the present invention. Note that the light-emitting device can be used for electronic devices and automobiles in a variety of fields without being limited to the electronic devices described in this embodiment.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 7

In this embodiment, a structure of a lighting device fabricated using the light-emitting element which is one embodiment of the present invention will be described with reference to FIGS. **11**A to **11**D.

FIGS. **11**A to **11**D are examples of cross-sectional views of lighting devices. FIGS. **11**A and **11**B illustrate bottom-emission lighting devices in which light is extracted from the substrate side, and FIGS. **11**C and **11**D illustrate top-emission lighting devices in which light is extracted from the sealing substrate side.

A lighting device **4000** illustrated in FIG. **11**A includes a light-emitting element **4002** over a substrate **4001**. In addition, the lighting device **4000** includes a substrate **4003** with unevenness on the outside of the substrate **4001**. The light-emitting element **4002** includes a first electrode **4004**, an EL layer **4005**, and a second electrode **4006**.

The first electrode **4004** is electrically connected to an electrode **4007**, and the second electrode **4006** is electrically connected to an electrode **4008**. In addition, an auxiliary wiring **4009** electrically connected to the first electrode **4004** may be provided. Note that an insulating layer **4010** is formed over the auxiliary wiring **4009**.

The substrate **4001** and a sealing substrate **4011** are bonded to each other by a sealant **4012**. A desiccant **4013** is preferably provided between the sealing substrate **4011** and the light-emitting element **4002**. The substrate **4003** has the unevenness illustrated in FIG. **11**A, whereby the extraction efficiency of light emitted from the light-emitting element **4002** can be increased.

Instead of the substrate **4003**, a diffusion plate **4015** may be provided on the outside of the substrate **4001** as in a lighting device **4100** illustrated in FIG. **11**B.

A lighting device **4200** illustrated in FIG. **11**C includes a light-emitting element **4202** over a substrate **4201**. The light-emitting element **4202** includes a first electrode **4204**, an EL layer **4205**, and a second electrode **4206**.

The first electrode **4204** is electrically connected to an electrode **4207**, and the second electrode **4206** is electrically connected to an electrode **4208**. An auxiliary wiring **4209** electrically connected to the second electrode **4206** may be provided. An insulating layer **4210** may be provided under the auxiliary wiring **4209**.

The substrate **4201** and a sealing substrate **4211** with unevenness are bonded to each other by a sealant **4212**. A barrier film **4213** and a planarization film **4214** may be provided between the sealing substrate **4211** and the light-emitting element **4202**. The sealing substrate **4211** has the unevenness illustrated in FIG. **11**C, whereby the extraction efficiency of light emitted from the light-emitting element **4202** can be increased.

Instead of the sealing substrate **4211**, a diffusion plate **4215** may be provided over the light-emitting element **4202** as in a lighting device **4300** illustrated in FIG. **11**D.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 8

In this embodiment, examples of a lighting device which is an application of the light-emitting device of one embodiment of the present invention will be described with reference to FIG. **12**.

FIG. **12** illustrates an example in which the light-emitting device is used in an indoor lighting device **8001**. Since the light-emitting device can have a large area, it can be used for a lighting device having a large area. In addition, with the use of a housing with a curved surface, a lighting device **8002** in which a light-emitting region has a curved surface can also be obtained. A light-emitting element included in the light-emitting device described in this embodiment is in a thin film form, which allows the housing to be designed more freely. Thus, the lighting device can be elaborately designed in a variety of ways. In addition, a wall of the room may be provided with a lighting device **8003**.

Besides the above examples, when the light-emitting device is used as part of furniture in a room, a lighting device that functions as the furniture can be obtained.

In this manner, a variety of lighting devices to which the light-emitting device is applied can be obtained.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 9

In this embodiment, touch panels including a light-emitting element of one embodiment of the present invention or a light-emitting device of one embodiment of the present invention will be described with reference to FIGS. **13**A and **13**B, FIGS. **14**A and **14**B, FIGS. **15**A and **15**B, FIGS. **16**A and **16**B, and FIG. **17**.

FIGS. **13**A and **13**B are perspective views of a touch panel **2000**. Note that FIGS. **13**A and **13**B illustrate typical components of the touch panel **2000** for simplicity.

The touch panel **2000** includes a display panel **2501** and a touch sensor **2595** (see FIG. **13**B). Furthermore, the touch panel **2000** includes substrates **2510**, **2570**, and **2590**.

The display panel **2501** includes a plurality of pixels over the substrate **2510**, and a plurality of wirings **2511** through which signals are supplied to the pixels. The plurality of wirings **2511** are led to a peripheral portion of the substrate **2510**, and part of the plurality of wirings **2511** forms a terminal **2519**. The terminal **2519** is electrically connected to an FPC **2509**(**1**).

The substrate **2590** includes the touch sensor **2595** and a plurality of wirings **2598** electrically connected to the touch sensor **2595**. The plurality of wirings **2598** are led to a peripheral portion of the substrate **2590**, and part of the plurality of wirings **2598** forms a terminal **2599**. The terminal **2599** is electrically connected to an FPC **2509**(**2**). Note that in FIG. **13**B, electrodes, wirings, and the like of the touch sensor **2595** provided on the back side of the substrate **2590** (the side facing the substrate **2510**) are indicated by solid lines for clarity.

As the touch sensor **2595**, a capacitive touch sensor can be used, for example. Examples of the capacitive touch sensor are a surface capacitive touch sensor, a projected capacitive touch sensor, and the like.

Examples of the projected capacitive touch sensor are a self-capacitive touch sensor, a mutual capacitive touch sensor, and the like, which differ mainly in the driving method. The use of a mutual capacitive touch sensor is preferable because multiple points can be sensed simultaneously.

First, an example of using a projected capacitive touch sensor is described with reference to FIG. **13**B. Note that in the case of a projected capacitive touch sensor, a variety of sensors that can sense the closeness or the contact of a sensing target such as a finger can be used.

The projected capacitive touch sensor **2595** includes electrodes **2591** and **2592**. The electrodes **2591** are electrically connected to any of the plurality of wirings **2598**, and the electrodes **2592** are electrically connected to any of the other wirings **2598**. The electrodes **2592** each have a shape of a plurality of quadrangles arranged in one direction with one corner of a quadrangle connected to one corner of another quadrangle with a wiring **2594** in one direction, as illustrated in FIGS. **13**A and **13**B. In the same manner, the electrodes **2591** each have a shape of a plurality of quadrangles arranged with one corner of a quadrangle connected to one corner of another quadrangle; however, the direction in which the electrodes **2591** are connected is a direction crossing the direction in which the electrodes **2592** are connected. Note that the direction in which the electrodes **2591** are connected and the direction in which the electrodes **2592** are connected are not necessarily perpendicular to each other, and the electrodes **2591** may be arranged to intersect with the electrodes **2592** at an angle greater than 0° and less than 90°.

The intersecting area of the wiring **2594** and one of the electrodes **2592** is preferably as small as possible. Such a structure allows a reduction in the area of a region where the electrodes are not provided, reducing unevenness in transmittance. As a result, unevenness in the luminance of light from the touch sensor **2595** can be reduced.

Note that the shapes of the electrodes **2591** and the **2592** are not limited to the above-described shapes and can be any of a variety of shapes. For example, the plurality of electrodes **2591** may be provided so that a space between the electrodes **2591** are reduced as much as possible, and the plurality of electrodes **2592** may be provided with an insulating layer sandwiched between the electrodes **2591** and **2592**. In that case, it is preferable to provide, between two adjacent electrodes **2592**, a dummy electrode which is electrically insulated from these electrodes because the area of a region having a different transmittance can be reduced.

Next, the touch panel **2000** is described in detail with reference to FIGS. **14**A and **14**B. FIGS. **14**A and **14**B are cross-sectional views taken along the dashed-dotted line X1-X2 in FIG. **13**A.

The touch panel **2000** includes the touch sensor **2595** and the display panel **2501**.

The touch sensor **2595** includes the electrodes **2591** and **2592** that are provided in a staggered arrangement and in contact with the substrate **2590**, an insulating layer **2593** covering the electrodes **2591** and **2592**, and the wiring **2594** that electrically connects the adjacent electrodes **2591** to each other. Between the adjacent electrodes **2591**, the electrode **2592** is provided.

The electrodes **2591** and **2592** can be formed using a light-transmitting conductive material. As a light-transmitting conductive material, a conductive oxide such as indium oxide, indium tin oxide, indium zinc oxide, zinc oxide, or zinc oxide to which gallium is added can be used. A graphene compound may be used as well. When a graphene compound is used, it can be formed, for example, by reducing a graphene oxide film. As a reducing method, a method with application of heat, a method with laser irradiation, or the like can be employed.

For example, the electrodes **2591** and **2592** can be formed by depositing a light-transmitting conductive material on the substrate **2590** by a sputtering method and then removing an unneeded portion by any of various patterning techniques such as photolithography.

Examples of a material for the insulating layer **2593** are a resin such as acrylic or epoxy resin, a resin having a siloxane bond, and an inorganic insulating material such as silicon oxide, silicon oxynitride, or aluminum oxide.

The adjacent electrodes **2591** are electrically connected to each other with the wiring **2594** formed in part of the insulating layer **2593**. Note that a material for the wiring **2594** preferably has higher conductivity than materials for the electrodes **2591** and **2592** to reduce electrical resistance.

One wiring **2598** is electrically connected to any of the electrodes **2591** and **2592**. Part of the wiring **2598** serves as a terminal. For the wiring **2598**, a metal material such as aluminum, gold, platinum, silver, nickel, titanium, tungsten, chromium, molybdenum, iron, cobalt, copper, or palladium or an alloy material containing any of these metal materials can be used.

Through the terminal **2599**, the wiring **2598** and the FPC **2509(2)** are electrically connected to each other. The terminal **2599** can be formed using any of various kinds of anisotropic conductive films (ACF), anisotropic conductive pastes (ACP), and the like.

An adhesive layer **2597** is provided in contact with the wiring **2594**. That is, the touch sensor **2595** is attached to the display panel **2501** so that they overlap with each other with the adhesive layer **2597** provided therebetween. Note that the substrate **2570** as illustrated in FIG. **14**A may be provided over the surface of the display panel **2501** that is in contact with the adhesive layer **2597**; however, the substrate **2570** is not always needed.

The adhesive layer **2597** has a light-transmitting property. For example, a thermosetting resin or an ultraviolet curable resin can be used; specifically, a resin such as an acrylic-based resin, a urethane-based resin, an epoxy-based resin, or a siloxane-based resin can be used.

The display panel **2501** in FIG. **14**A includes, between the substrate **2510** and the substrate **2570**, a plurality of pixels arranged in a matrix and a driver circuit. Each pixel includes a light-emitting element and a pixel circuit driving the light-emitting element.

In FIG. **14**A, a pixel **2502**R is shown as an example of the pixel of the display panel **2501**, and a scan line driver circuit **2503***g* is shown as an example of the driver circuit.

The pixel **2502**R includes a light-emitting element **2550**R and a transistor **2502***t* that can supply electric power to the light-emitting element **2550**R.

The transistor **2502***t* is covered with an insulating layer **2521**. The insulating layer **2521** covers unevenness caused by the transistor and the like that have been already formed to provide a flat surface. The insulating layer **2521** may serve also as a layer for preventing diffusion of impurities. That is preferable because a reduction in the reliability of the transistor or the like due to diffusion of impurities can be prevented.

The light-emitting element **2550**R is electrically connected to the transistor **2502***t* through a wiring. It is one electrode of the light-emitting element **2550**R that is directly connected to the wiring. An end portion of the one electrode of the light-emitting element **2550**R is covered with an insulator **2528**.

The light-emitting element **2550**R includes an EL layer between a pair of electrodes. A coloring layer **2567**R is provided to overlap with the light-emitting element **2550**R, and part of light emitted from the light-emitting element **2550**R is transmitted through the coloring layer **2567**R and extracted in the direction indicated by an arrow in the drawing. A light-blocking layer **2567**BM is provided at an end portion of the coloring layer, and a sealing layer **2560** is provided between the light-emitting element **2550**R and the coloring layer **2567**R.

Note that when the sealing layer **2560** is provided on the side from which light from the light-emitting element **2550**R is extracted, the sealing layer **2560** preferably has a light-transmitting property. The sealing layer **2560** preferably has a higher refractive index than the air.

The scan line driver circuit **2503***g* includes a transistor **2503***t* and a capacitor **2503***c*. Note that the driver circuit and the pixel circuits can be formed in the same process over the same substrate. Thus, in a manner similar to that of the transistor **2502***t* in the pixel circuit, the transistor **2503***t* in the driver circuit (scan line driver circuit **2503***g*) is also covered with the insulating layer **2521**.

The wirings **2511** through which a signal can be supplied to the transistor **2503***t* are provided. The terminal **2519** is provided in contact with the wiring **2511**. The terminal **2519** is electrically connected to the FPC **2509(1)**, and the FPC **2509(1)** has a function of supplying signals such as an image signal and a synchronization signal. Note that a printed wiring board (PWB) may be attached to the FPC **2509(1)**.

Although the case where the display panel **2501** illustrated in FIG. **14**A includes a bottom-gate transistor is described, the structure of the transistor is not limited thereto, and any of transistors with various structures can be used. In each of the transistors **2502***t* and **2503***t* illustrated in FIG. **14**A, a semiconductor layer containing an oxide semiconductor can be used for a channel region. Alternatively, a semiconductor layer containing amorphous silicon or a semiconductor layer containing polycrystalline silicon that is obtained by crystallization process such as laser annealing can be used for a channel region.

FIG. **14**B illustrates the structure of the display panel **2501** that includes a top-gate transistor instead of the bottom-gate transistor illustrated in FIG. **14**A. The kind of the semiconductor layer that can be used for the channel region does not depend on the structure of the transistor.

In the touch panel **2000** illustrated in FIG. **14**A, an anti-reflection layer **2567***p* overlapping with at least the pixel is preferably provided on a surface of the touch panel on the side from which light from the pixel is extracted, as illustrated in FIG. **14**A. As the anti-reflection layer **2567***p*, a circular polarizing plate or the like can be used.

For the substrates **2510**, **2570**, and **2590** in FIG. **14**A, for example, a flexible material having a vapor permeability of 1×10^{-5} g/(m^2·day) or lower, preferably 1×10^{-6} g/(m^2·day) or lower, can be favorably used. Alternatively, it is preferable to use the materials that make these substrates have substantially the same coefficient of thermal expansion. For example, the coefficients of linear expansion of the materials are 1×10^{-3}/K or lower, preferably 5×10^{-5}/K or lower and further preferably 1×10^{-5}/K or lower.

Next, a touch panel **2000** having a structure different from that of the touch panel **2000** illustrated in FIGS. **14**A and **14**B is described with reference to FIGS. **15**A and **15**B. It can be used as a touch panel as well as the touch panel **2000**.

FIGS. **15**A and **15**B are cross-sectional views of the touch panel **2000**. In the touch panel **2000'** illustrated in FIGS. **15**A and **15**B, the position of the touch sensor **2595** relative to the display panel **2501** is different from that in the touch panel **2000** illustrated in FIGS. **14**A and **14**B. Only different structures are described below, and the above description of the touch panel **2000** can be referred to for the other similar structures.

The coloring layer **2567**R overlaps with the light-emitting element **2550**R. Light from the light-emitting element **2550**R illustrated in FIG. **15**A is emitted to the side where the transistor **2502***t* is provided. That is, (part of) light emitted from the light-emitting element **2550**R passes through the coloring layer **2567**R and is extracted in the direction indicated by an arrow in FIG. **15**A. Note that the light-blocking layer **2567**BM is provided at an end portion of the coloring layer **2567**R.

The touch sensor **2595** is provided on the transistor **2502***t* side (the far side from the light-emitting element **2550**R) of the display panel **2501** (see FIG. **15**A).

The adhesive layer **2597** is in contact with the substrate **2510** of the display panel **2501** and attaches the display panel **2501** and the touch sensor **2595** to each other in the structure illustrated in FIG. **15**A. The substrate **2510** is not necessarily provided between the display panel **2501** and the touch sensor **2595** that are attached to each other by the adhesive layer **2597**.

As in the touch panel **2000**, transistors with a variety of structures can be used for the display panel **2501** in the touch panel **2000'**. Although a bottom-gate transistor is used in FIG. **15**A, a top-gate transistor may be used as illustrated in FIG. **15**B.

An example of a driving method of the touch panel is described with reference to FIGS. **16**A and **16**B.

FIG. **16**A is a block diagram illustrating the structure of a mutual capacitive touch sensor. FIG. **16**A illustrates a pulse voltage output circuit **2601** and a current sensing circuit **2602**. Note that in the example of FIG. **16**A, six wirings **X1**-**X6** represent electrodes **2621** to which a pulse voltage is supplied, and six wirings **Y1**-**Y6** represent electrodes **2622** that sense a change in current. FIG. **16**A also illustrates a capacitor **2603** which is formed in a region where the electrodes **2621** and **2622** overlap with each other. Note that functional replacement between the electrodes **2621** and **2622** is possible.

The pulse voltage output circuit **2601** is a circuit for sequentially applying a pulse voltage to the wirings X**1** to X**6**. By application of a pulse voltage to the wirings X**1** to X**6**, an electric field is generated between the electrodes **2621** and **2622** of the capacitor **2603**. When the electric field between the electrodes is shielded, for example, a change occurs in the capacitor **2603** (mutual capacitance). The approach or contact of a sensing target can be sensed by utilizing this change.

The current sensing circuit **2602** is a circuit for sensing changes in current flowing through the wirings Y**1** to Y**6** that are caused by the change in mutual capacitance in the capacitor **2603**. No change in current value is sensed in the wirings Y**1** to Y**6** when there is no approach or contact of a sensing target, whereas a decrease in current value is sensed when mutual capacitance is decreased owing to the approach or contact of a sensing target. Note that an integrator circuit or the like is used for sensing of current.

FIG. **16**B is a timing chart showing input and output waveforms in the mutual capacitive touch sensor illustrated in FIG. **16**A. In FIG. **16**B, sensing of a sensing target is performed in all the rows and columns in one frame period. FIG. **16**B shows a period when a sensing target is not sensed (not touched) and a period when a sensing target is sensed (touched). Sensed current values of the wirings Y**1** to Y**6** are shown as the waveforms of voltage values.

A pulse voltage is sequentially applied to the wirings X**1** to X**6**, and the waveforms of the wirings Y**1** to Y**6** change in accordance with the pulse voltage. When there is no approach or contact of a sensing target, the waveforms of the wirings Y**1** to Y**6** change uniformly in accordance with changes in the voltages of the wirings X**1** to X**6**. The current value is decreased at the point of approach or contact of a sensing target and accordingly the waveform of the voltage value changes. By sensing a change in mutual capacitance in this manner, the approach or contact of a sensing target can be sensed.

Although FIG. **16**A illustrates a passive touch sensor in which only the capacitor **2603** is provided at the intersection of wirings as a touch sensor, an active touch sensor including a transistor and a capacitor may be used. FIG. **17** is a sensor circuit included in an active touch sensor.

The sensor circuit illustrated in FIG. **17** includes the capacitor **2603** and transistors **2611**, **2612**, and **2613**.

A signal G**2** is input to a gate of the transistor **2613**. A voltage VRES is applied to one of a source and a drain of the transistor **2613**, and one electrode of the capacitor **2603** and a gate of the transistor **2611** are electrically connected to the other of the source and the drain of the transistor **2613**. One of a source and a drain of the transistor **2611** is electrically connected to one of a source and a drain of the transistor **2612**, and a voltage VSS is applied to the other of the source and the drain of the transistor **2611**. A signal G**1** is input to a gate of the transistor **2612**, and a wiring ML is electrically connected to the other of the source and the drain of the transistor **2612**. The voltage VSS is applied to the other electrode of the capacitor **2603**.

Next, the operation of the sensor circuit illustrated in FIG. **17** is described. First, a potential for turning on the transistor **2613** is supplied as the signal G**2**, and a potential with respect to the voltage VRES is thus applied to a node n connected to the gate of the transistor **2611**. Then, a potential for turning off the transistor **2613** is applied as the signal G**2**, whereby the potential of the node n is maintained. Then, mutual capacitance of the capacitor **2603** changes owing to the approach or contact of a sensing target such as a finger; accordingly, the potential of the node n is changed from VRES.

In reading operation, a potential for turning on the transistor **2612** is supplied as the signal G**1**. A current flowing through the transistor **2611**, that is, a current flowing through the wiring ML is changed in accordance with the potential of the node n. By sensing this current, the approach or contact of a sensing target can be sensed.

In each of the transistors **2611**, **2612**, and **2613**, an oxide semiconductor layer is preferably used as a semiconductor layer in which a channel region is formed. In particular, such a transistor is preferably used as the transistor **2613**, so that the potential of the node n can be held for a long time and the frequency of operation of resupplying VRES to the node n (refresh operation) can be reduced.

At least part of this embodiment can be implemented in combination with any of the embodiments described in this specification as appropriate.

Embodiment 10

In this embodiment, as a display device including a light-emitting element, a display device which includes a reflective liquid crystal element and a light-emitting element and is capable of performing display both in a transmissive mode and a reflective mode is described with reference to FIGS. **36**A, **36**B**1**, and **36**B**2**, FIG. **37**, and FIG. **38**.

The display device described in this embodiment can be driven with extremely low power consumption for display using the reflective mode in a bright place such as outdoors. Meanwhile, in a dark place such as indoors at night, image can be displayed at an optimal luminance with the use of the transmissive mode. Thus, by combination of these modes, the display device can display an image with lower power consumption and a higher contrast compared to a conventional display panel.

As an example of the display device of this embodiment, description is made on a display device in which a liquid crystal element provided with a reflective electrode and a light-emitting element are stacked and an opening of the reflective electrode is provided in a position overlapping with the light-emitting element. Visible light is reflected by the reflective electrode in the reflective mode and light emitted from the light-emitting element is emitted through the opening of the reflective electrode in the transmissive mode. Note that transistors used for driving these elements (the liquid crystal element and the light-emitting element) are preferably formed on the same plane. It is preferable that the liquid crystal element and the light-emitting element be stacked through an insulating layer.

FIG. **36**A is a block diagram illustrating a display device described in this embodiment. A display device **600** includes a circuit (G) **601**, a circuit (S) **602**, and a display portion **603**. In the display portion **603**, a plurality of pixels **604** are arranged in an R direction and a C direction in a matrix. A plurality of wirings G**1**, wirings G**2**, wirings ANO, and wirings CSCOM are electrically connected to the circuit (G) **601**. These wirings are also electrically connected to the plurality of pixels **604** arranged in the R direction. A plurality of wirings S**1** and wirings S**2** are electrically connected to the circuit (S) **602**, and these wirings are also electrically connected to the plurality of pixels **604** arranged in the C direction.

Each of the plurality of pixels **604** includes a liquid crystal element and a light-emitting element. The liquid crystal element and the light-emitting element include portions overlapping with each other.

FIG. **36**B**1** shows the shape of a conductive film **605** serving as a reflective electrode of the liquid crystal element included in the pixel **604**. Note that an opening **607** is provided in a position **606** which is part of the conductive film **605** and which overlaps with the light-emitting element. That is, light emitted from the light-emitting element is emitted through the opening **607**.

The pixels **604** in FIG. **36**B**1** are arranged such that adjacent pixels **604** in the R direction exhibit different colors. Furthermore, the openings **607** are provided so as not to be arranged in a line in the R direction. Such arrangement has an effect of suppressing crosstalk between the light emitting elements of adjacent pixels **604**.

The opening **607** can have a polygonal shape, a quadrangular shape, an elliptical shape, a circular shape, a cross shape, a stripe shape, or a slit-like shape, for example.

FIG. **36**B**2** illustrates another example of the arrangement of the conductive films **605**.

The ratio of the opening **607** to the total area of the conductive film **605** (excluding the opening **607**) affects the display of the display device. That is, a problem is caused in that as the area of the opening **607** is larger, the display using the liquid crystal element becomes darker; in contrast, as the area of the opening **607** is smaller, the display using the light-emitting element becomes darker. Furthermore, in addition to the problem of the ratio of the opening, a small area of the opening **607** itself also causes a problem in that extraction efficiency of light emitted from the light-emitting element is decreased. The ratio of opening **607** to the total area of the conductive film **605** (other than the opening **607**) is preferably 5% or more and 60% or less for maintaining display quality at the time of combination of the liquid crystal element and the light-emitting element.

Next, an example of a circuit configuration of the pixel **604** is described with reference to FIG. **37**. FIG. **37** shows two adjacent pixels **604**.

The pixel **604** includes a transistor SW**1**, a capacitor C**1**, a liquid crystal element **610**, a transistor SW**2**, a transistor M, a capacitor C**2**, a light-emitting element **611**, and the like. Note that these components are electrically connected to any of the wiring G**1**, the wiring G**2**, the wiring ANO, the wiring CSCOM, the wiring S**1**, and the wiring S**2** in the pixel **604**. The liquid crystal element **610** and the light-emitting element **611** are electrically connected to a wiring VCOM**1** and a wiring VCOM**2**, respectively.

A gate of the transistor SW**1** is connected to the wiring G**1**. One of a source and a drain of the transistor SW**1** is connected to the wiring S**1**, and the other of the source and the drain is connected to one electrode of the capacitor C**1** and one electrode of the liquid crystal element **610**. The other electrode of the capacitor C**1** is electrically connected to the wiring CSCOM. The other electrode of the liquid crystal element **610** is connected to the wiring VCOM**1**.

A gate of the transistor SW**2** is connected to the wiring G**2**. One of a source and a drain of the transistor SW**2** is connected to the wiring S**2**, and the other of the source and the drain is connected to one electrode of the capacitor C**2** and a gate of the transistor M. The other electrode of the capacitor C**2** is connected to one of a source and a drain of the transistor M and the wiring ANO. The other of the source and the drain of the transistor M is connected to one electrode of the light-emitting element **611**. Furthermore, the other electrode of the light-emitting element **611** is connected to the wiring VCOM**2**.

Note that the transistor M includes two gates between which a semiconductor is provided and which are electrically connected to each other. With such a structure, the amount of current flowing through the transistor M can be increased.

The on/off state of the transistor SW**1** is controlled by a signal from the wiring G**1**. A predetermined potential is supplied from the wiring VCOM**1**. Furthermore, orientation of liquid crystals of the liquid crystal element **610** can be controlled by a signal from the wiring S**1**. A predetermined potential is supplied from the wiring CSCOM.

The on/off state of the transistor SW**2** is controlled by a signal from the wiring G**2**. By the difference between the potentials applied from the wiring VCOM**2** and the wiring

ANO, the light-emitting element **611** can emit light. Furthermore, the on/off state of the transistor M is controlled by a signal from the wiring S**2**.

Accordingly, in the structure of this embodiment, in the case of the reflective mode, the liquid crystal element **610** is controlled by the signals supplied from the wiring G**1** and the wiring S**1** and optical modulation is utilized, whereby display can be performed. In the case of the transmissive mode, the light-emitting element **611** can emit light when the signals are supplied from the wiring G**2** and the wiring S**2**. In the case where both modes are performed at the same time, desired driving can be performed based on the signals from the wiring G**1**, the wiring G**2**, the wiring S**1**, and the wiring S**2**.

Next, specific description will be given with reference to FIG. **38**, a schematic cross-sectional view of the display device **600** described in this embodiment.

The display device **600** includes a light-emitting element **623** and a liquid crystal element **624** between substrates **621** and **622**. Note that the light-emitting element **623** and the liquid crystal element **624** are formed with an insulating layer **625** positioned therebetween. That is, the light-emitting element **623** is positioned between the substrate **621** and the insulating layer **625**, and the liquid crystal element **624** is positioned between the substrate **622** and the insulating layer **625**.

A transistor **615**, a transistor **616**, a transistor **617**, a coloring layer **628**, and the like are provided between the insulating layer **625** and the light-emitting element **623**.

A bonding layer **629** is provided between the substrate **621** and the light-emitting element **623**. The light-emitting element **623** includes a conductive layer **630** serving as one electrode, an EL layer **631**, and a conductive layer **632** serving as the other electrode which are stacked in this order over the insulating layer **625**. In the light-emitting element **623** that is a bottom emission light-emitting element, the conductive layer **632** and the conductive layer **630** contain a material that reflects visible light and a material that transmits visible light, respectively. Light emitted from the light-emitting element **623** is transmitted through the coloring layer **628** and the insulating layer **625** and then transmitted through the liquid crystal element **624** via an opening **633**, thereby being emitted to the outside of the substrate **622**.

In addition to the liquid crystal element **624**, a coloring layer **634**, a light-blocking layer **635**, an insulating layer **646**, a structure **636**, and the like are provided between the insulating layer **625** and the substrate **622**. The liquid crystal element **624** includes a conductive layer **637** serving as one electrode, a liquid crystal **638**, a conductive layer **639** serving as the other electrode, alignment films **640** and **641**, and the like. Note that the liquid crystal element **624** is a reflective liquid crystal element and the conductive layer **639** serves as a reflective electrode; thus, the liquid crystal element **624** and the conductive layer **639** are formed using a material with high reflectivity. Furthermore, the conductive layer **637** serves as a transparent electrode, and thus is formed using a material that transmits visible light. Alignment films **640** and **641** may be provided on the conductive layers **637** and **638** and in contact with the liquid crystal layer **638**. The insulating layer **646** is provided so as to cover the coloring layer **634** and the light-blocking **635** and serves as an overcoat layer. Note that the alignment films **640** and **641** are not necessarily provided.

The opening **633** is provided in part of the conductive layer **639**. A conductive layer **643** is provided in contact with the conductive layer **639** and has a light-transmitting property because of being formed using a material transmitting visible light.

The structure **636** serves as a spacer that prevents the substrate **622** from coming closer to the insulating layer **625** than required. The structure **636** is not necessarily provided.

One of a source and a drain of the transistor **615** is electrically connected to the conductive layer **630** in the light-emitting element **623**. For example, the transistor **615** corresponds to the transistor M in FIG. **37**.

One of a source and a drain of the transistor **616** is electrically connected to the conductive layer **639** and the conductive layer **643** in the liquid crystal element **624** through a terminal portion **618**. That is, the terminal portion **618** electrically connects the conductive layers provided on both surfaces of the insulating layer **625**. The transistor **616** corresponds to the switch **SW1** in FIG. **37**.

A terminal portion **619** is provided in a region where the substrates **621** and **622** do not overlap with each other. Similarly to the terminal portion **618**, the terminal portion **619** electrically connects the conductive layers provided on both surfaces of the insulating layer **625**. The terminal portion **619** is electrically connected to a conductive layer obtained by processing the same conductive film as the conductive layer **643**. Thus, the terminal portion **619** and the FPC **644** can be electrically connected to each other through a connection layer **645**.

A connection portion **647** is provided in part of a region where a bonding layer **642** is provided. In the connection portion **647**, the conductive layer obtained by processing the same conductive film as the conductive layer **643** and part of the conductive layer **637** are electrically connected with a connector **648**. Accordingly, a signal or a potential input from the FPC **644** can be supplied to the conductive layer **637** through the connection portion **647**.

The structure **636** is provided between the conductive layer **637** and the conductive layer **643**. The structure **636** maintains a cell gap of the liquid crystal element **624**.

As the conductive layer **643**, a metal oxide, a metal nitride, or an oxide such as an oxide semiconductor whose resistance is reduced is preferably used. In the case of using an oxide semiconductor, a material in which at least one of the concentrations of hydrogen, boron, phosphorus, nitrogen, and other impurities and the number of oxygen vacancies is made to be higher than those in a semiconductor layer of a transistor is used for the conductive layer **643**.

Note that the structure described in this embodiment can be combined as appropriate with any of the structures described in the other embodiments.

Embodiment 11

In this embodiment, a light-emitting element is described. The light-emitting element described in this embodiment has a structure different from that described in Embodiment 2. An element structure and a manufacturing method of the light-emitting element is described with reference to FIGS. **39**A and **39**B. For the portions similar to those in Embodiments 2, the description of Embodiments 2 can be referred to and description is omitted.

The light-emitting element described in this embodiment has a structure in which an EL layer **3202** including a light-emitting layer **3213** is sandwiched between a pair of electrodes (a cathode **3201** and an anode **3203**) formed over a substrate **3200**. The EL layer **3202** can be formed by stacking a light-emitting layer, a hole-injection layer, a hole-transport layer, an electron-injection layer, an electron-transport layer, and the like as in the EL layer described in Embodiment 2.

In this embodiment, as shown in FIG. **39**A, description is made on the light-emitting element having a structure in which the EL layer **3202** including an electron-injection layer **3214**, the light-emitting layer **3213**, a hole-transport layer **3215**, and a hole-injection layer **3216** are formed over the cathode **3201** in this order over the substrate **3200** and the anode **3203** is formed over the hole-injection layer **3216**. Here, though an electron-transport layer is not provided, the electron-injection layer **3214** can serve as the electron-transport layer with a material having a high electron-transport property.

In the above-described light-emitting element, current flows due to a potential difference applied between the cathode **3201** and the anode **3203**, and holes and electrons recombine in the EL layer **3202**, whereby light is emitted. Then, this light emission is extracted to the outside through one or both of the cathode **3201** and the anode **3203**. Therefore, one or both of the cathode **3201** and the anode **3203** are electrodes having light-transmitting properties; light can be extracted through the electrode having a light-transmitting property.

In the light-emitting element described in this embodiment, end portions of the cathode **3201** are covered with insulators **3217** as shown in FIG. **39**. Note that the insulators **3217** are formed so as to fill a space between adjacent cathodes **3201** (e.g., **3201***a* and **3201***b*) as shown in FIG. **39**B.

As the insulator **3217**, an inorganic compound or an organic compound having an insulating property can be used. As the organic compound, a photosensitive resin such as a resist material, e.g., an acrylic resin, a polyimide resin, a fluorine-based resin, or the like can be used. As the inorganic material, silicon oxide, silicon oxynitride, silicon nitride, or the like can be used, for example. Note that the insulator **3217** preferably has a water-repellent surface. As its treatment method, plasma treatment, chemical treatment (using an alkaline solution or an organic solvent), or the like can be employed.

In this embodiment, the electron-injection layer **3214** formed over the cathode **3201** is formed using a high molecular compound. It is preferable to use a high molecular compound which does not dissolve in the nonaqueous solvent and which has a high electron-transport property. Specifically, the electron-injection layer **3214** is formed using an appropriate combination of any of the materials (including not only a high molecular compound but also an alkali metal, an alkaline earth metal, or a compound thereof) which can be used for the electron-injection layer **115** and electron-transport layer **114** in Embodiment 2. The materials are dissolved in a polar solvent, and the layer is formed by a coating method.

Here, examples of the polar solvent include methanol, ethanol, propanol, isopropanol, butyl alcohol, ethylene glycol, and glycerin.

The light-emitting layer **3213** is formed over the electron-injection layer **3214**. The light-emitting layer **3213** is formed by depositing (or applying) ink in which any of the materials (a light-emitting substance) which can be used for the light-emitting layer **3213** in Embodiment 2 are combined as appropriate and dissolved (dispersed) in a polar solvent, by a wet method (an ink-jet method or a printing method). Although the electron-injection layer **3214** is used in common in light-emitting elements of different emission colors, a material corresponding to an emission color is selected for the light-emitting layer **3213**. As the polar solvent, an aromatic-based solvent such as toluene or xylene, or a heteroaromatic-based solvent such as pyridine can be used. Alternatively, a solvent such as hexane, 2-methylhexane cyclohexane, or chloroform can be used.

As shown in FIG. **39**B, the ink for forming the light-emitting layer **3213** is applied from a head portion **3300** of an apparatus for applying a solution (hereinafter referred to as solution application apparatus). Note that the head portion **3300** includes a plurality of spraying portions **3301***a* to **3301***c* for spraying ink, and piezoelectric elements **3302***a* to **3302***c* are provided for the spraying portions **3301***a* to **3301***c*. Furthermore, the spraying portions **3301***a* to **3301***c* are filled with respective ink **3303***a* to ink **3303***c* containing emission substances exhibiting different emission colors.

The ink **3303***a* to ink **3303***c* are sprayed from the respective spraying portions **3301***a* to **3301***c*, whereby light-emitting layers **3213***a* to **3213***c* emitting different colors are formed.

The hole-transport layer **3215** is formed over the light-emitting layer **3213**. The hole-transport layer **3215** can be formed by a combination of any of the materials which can be used for the hole-transport layer **3215** in Embodiment 2. The hole-transport layer **3215** can be formed by a vacuum evaporation method or a coating method. In the case of employing a coating method, the material which is dissolved in a solvent is applied to the light-emitting layer **3213** and the insulator **3217**. As a coating method, an ink-jet method, a spin coating method, a printing method, or the like can be used.

The hole-injection layer **3216** is formed over the hole-transport layer **3215**. The anode **3203** is formed over the hole-injection layer **3216**. They are formed using an appropriate combination of the materials described in Embodiment 2 by a vacuum evaporation method.

The light-emitting element can be formed through the above steps. Note that in the case of using an organometallic complex in the light-emitting layer, phosphorescence due to the organometallic complex is obtained. Thus, the light-emitting element can have higher efficiency than a light-emitting element formed using only fluorescent compounds.

Note that the structure described in this embodiment can be used in combination with any of the structures described in the other embodiments, as appropriate.

Embodiment 12

In this embodiment, an example of a lighting system to which a light-emitting element is applied, is described with reference to FIG. **40**.

As shown in FIG. **40**, a lighting system **700** includes a plurality of light emitting elements **701** and a control unit **702**. The control unit **702** is electrically connected to a power source **706**. The control unit **702** is electrically connected to each of the plurality of light-emitting elements **701** and controls lighting and extinction of each of the light-emitting elements **701** and control the luminance at the time of lighting. That is, the lighting system of this embodiment is configured to control emission of the light-emitting elements which are light sources of the lighting in accordance with external information. Here, the external information includes brightness information, lighting time information, and temperature information for example. To sense the external information, various parameters indicating such information can be used as signals.

Any of the light-emitting elements described in the other embodiments can be used for the light-emitting elements

701. An anode and a cathode of the light-emitting element are electrically connected to the control unit **702**, and a potential of one of the electrodes or potentials of both of the electrodes are controlled by a control signal from the control unit **702**, whereby lighting and extinction of the light-emitting elements **701** and the luminance at the time of lighting are controlled.

The control unit **702** includes a central processing unit (CPU) **703**, a memory **704**, and a communication unit **705**. Note that the communication unit **705** is electrically connected to a sensor **707** and receives lighting time information of the light-emitting elements **701** and external brightness information which are sensed by the sensor **707**.

As the sensor **707**, a photodiode, a light-receiving element such as a CdS photoconductive element, a charge coupled device (CCD), a sensor including a CMOS sensor, or the like which can sense the above-described information (e.g., lighting time information of the light-emitting element **701** and external brightness information) as a data signal, can be used.

In the memory **704**, a program for controlling lighting time of the light-emitting elements **701** is stored. The CPU **703** reads out from the memory **704** a signal (a lighting signal or an extinction signal) for lighting or extinguishing the plurality of light-emitting elements **701** in accordance with lighting time information of the light-emitting elements **701** input from the communication unit **705**, and executes driving of the light-emitting elements **701**. As an example of the program for controlling lighting time of the light-emitting elements **701**, a program with which consecutive lighting is completed in a certain period in order to prevent unnecessary lighting for a long time, is given.

Note that a program for controlling the luminance of the light-emitting elements may be stored in the memory **704**. In that case, the CPU **703** reads out signals (luminance control signals) for controlling the luminance of the plurality of light-emitting elements **701** in accordance with external brightness information input from the communication unit **705**, and executes driving of the light-emitting elements **701**. An example of the program for controlling the luminance of the light-emitting elements includes a program with which luminance can be strengthened or weakened on the basis of whether the external brightness information sensed by the sensor **707** reaches reference brightness set in advance. Furthermore, the signals for controlling the luminance of the plurality of light-emitting elements **701** may be different for each of the plurality of the light-emitting elements **701** or may be the same.

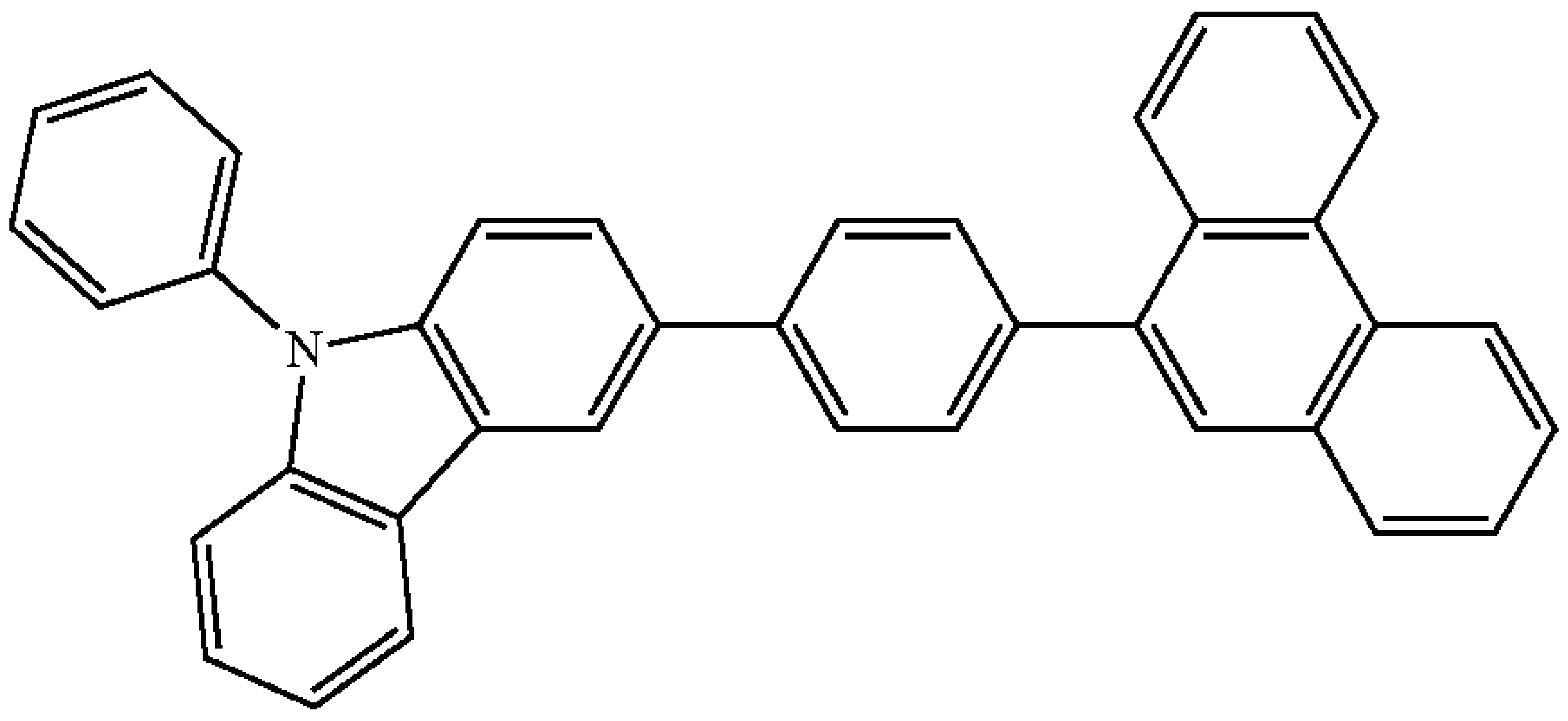
Specifically, in the case where the CPU **703** executes driving of the light-emitting element **701**, the signal read out from the memory **704** is converted by the CPU **703**, and the potential of one electrode of the light-emitting element is controlled.

Note that the plurality of the light-emitting elements **701** used in the lighting system of this embodiment may have the same structure or different structures. Furthermore, emission colors of the plurality of the light-emitting elements **701** may be the same or different from each other. The structure of the light-emitting element described in any of the other embodiments can be applied to the structure of the light-emitting element in this embodiment.

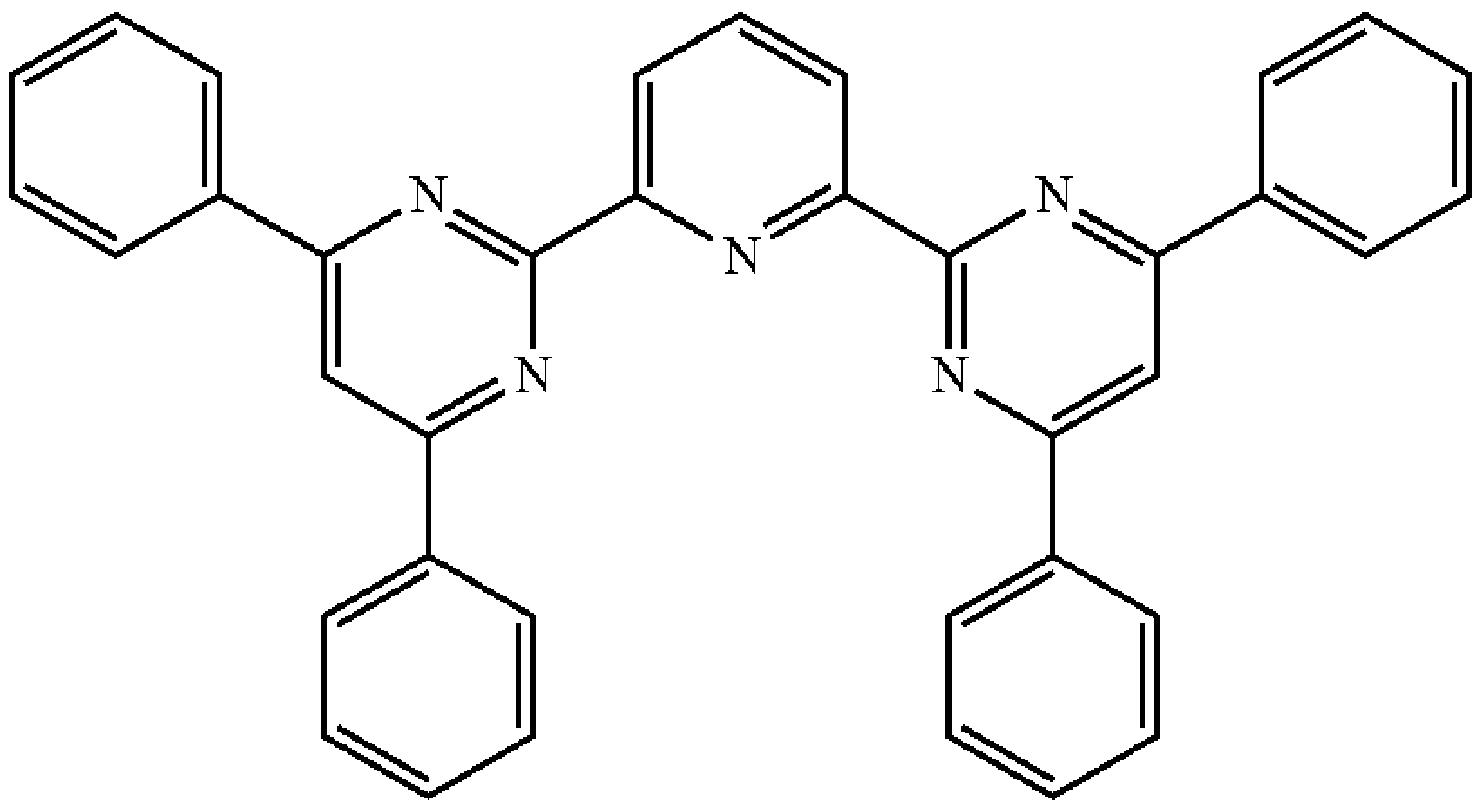
Note that the structure described in this embodiment can be used in combination with any of the structures described in the other embodiments, as appropriate.

Example 1

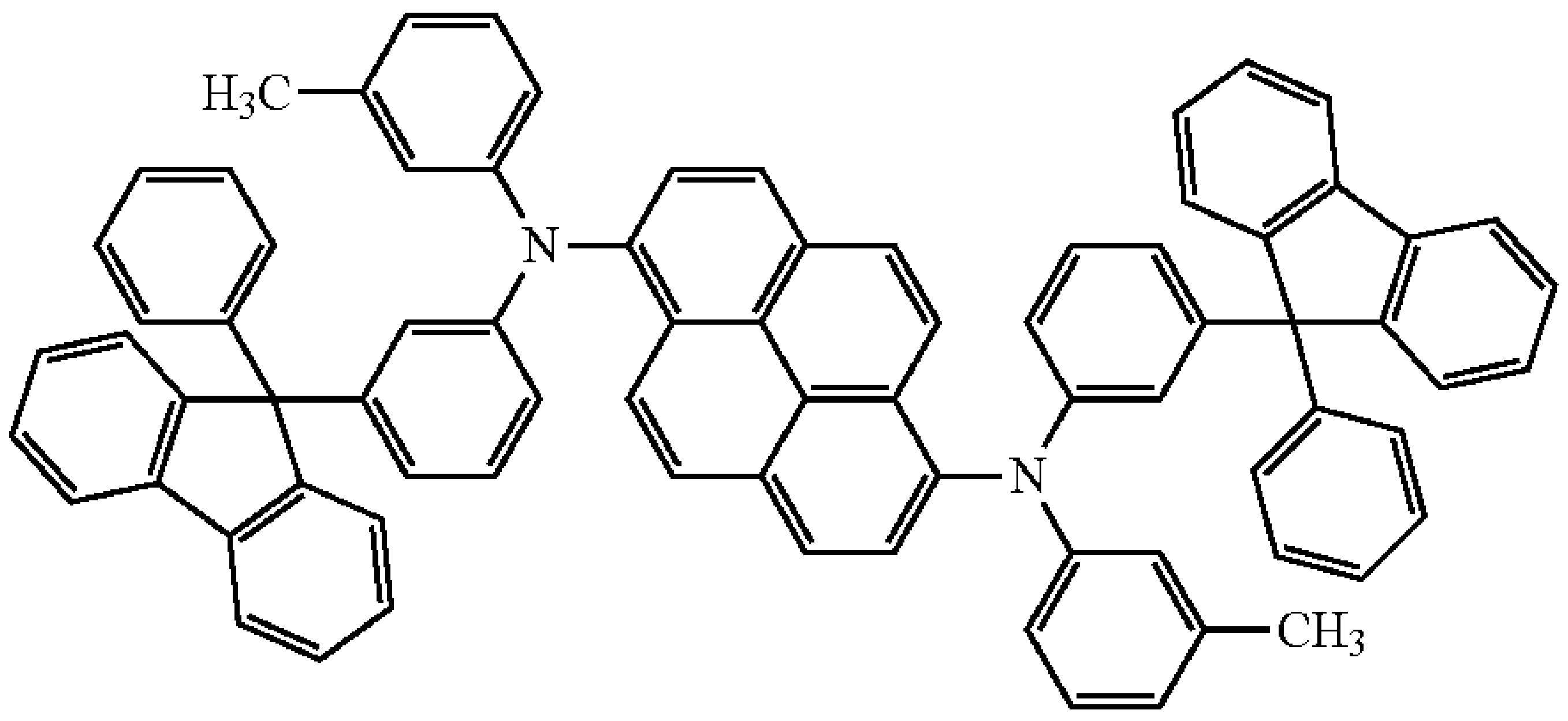
In this example, light-emitting elements were fabricated and characteristic thereof were shown. Specifically, Light-emitting element **1** in which only 1,5-bis[4-(9H-carbazole-9-yl)phenyl]anthracene (abbreviation: 1,5CzP2A) (Structural Formula: 100) was used in a light-emitting layer, Light-emitting element **2** in which 1,5CzP2A and 1,6mMemFLPAPrn that was a dopant (a light-emitting substance) were used in a light-emitting layer, Light-emitting element **3** in which only 1,8-bis[4-(9H-carbazol-9-yl)phenyl]anthracene (abbreviation: 1,8CzP2A) (Structural Formula 110) was used in a light-emitting layer, and Light-emitting element **4** in which 1,8CzP2A and 1,6mMemFLPAPrn that was a dopant (a light-emitting substance) were used in a light-emitting layer, were fabricated. Note that fabrication of Light-emitting elements **1** to **4** is described with reference to FIG. **18**. Chemical formulae of the materials used in this example are shown below.



PCPPn



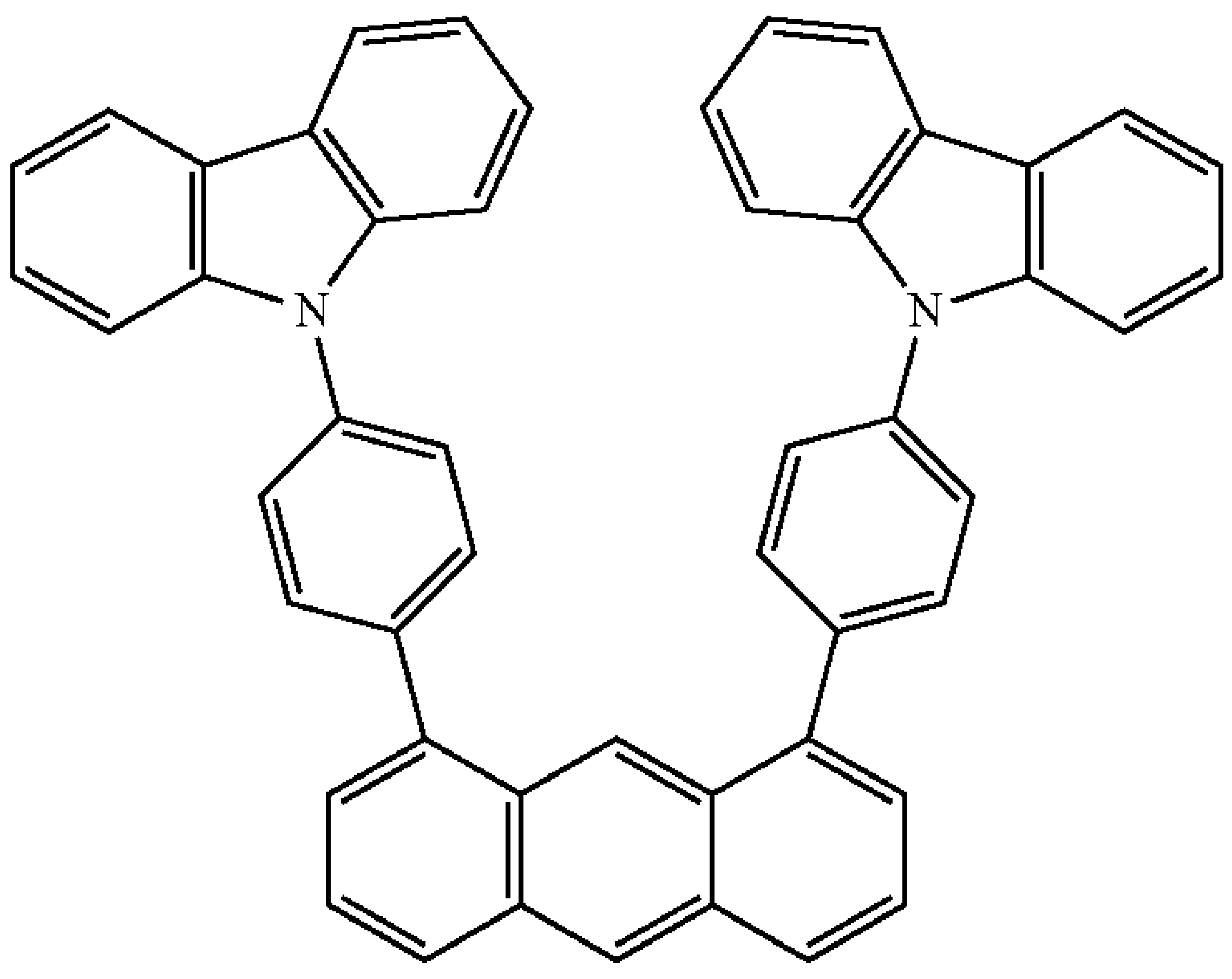
2,6(P2Pm)$_2$Py



1,6mMemFLPAPrn

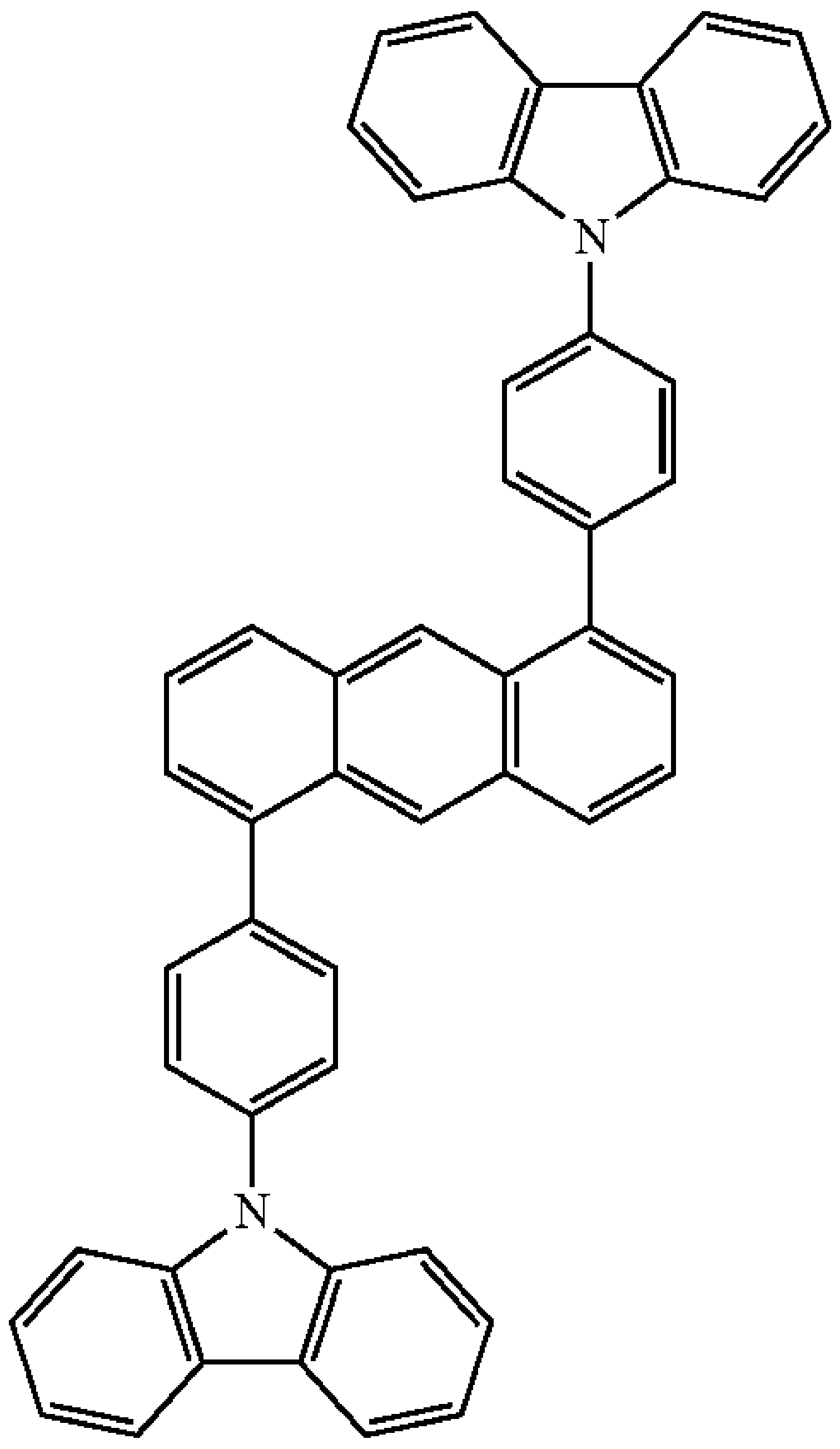
-continued

(110)



1,8CzP2A

(100)



1,5CzP2A

<<Fabrication of Light-Emitting Elements **1** to **4**>>

First, indium tin oxide (ITO) containing silicon oxide was deposited over a glass substrate **900** by a sputtering method, whereby a first electrode **901** functioning as an anode was formed. The thickness of the first electrode **901** was set to 70 nm and the area of the electrode was set to 2 mm×2 mm.

Next, as pretreatment for fabricating the light-emitting element **1** over the substrate **900**, UV ozone treatment was performed for 370 seconds after washing of a surface of the substrate with water and baking that was performed at 200° C. for 1 hour.

After that, the substrate **900** was transferred into a vacuum evaporation apparatus where the pressure had been reduced to approximately 1×10^{-4} Pa, and was subjected to vacuum baking at 170° C. for 30 minutes in a heating chamber of the vacuum evaporation apparatus. Then, the substrate **900** was cooled down for approximately 30 minutes.

Next, the substrate **900** over which the first electrode **901** was formed was fixed to a holder provided inside a vacuum evaporation apparatus so that the surface over which the first electrode was formed faced downward. In this example, a case will be described in which a hole-injection layer **911**, a hole-transport layer **912**, a light-emitting layer **913**, an electron-transport layer **914**, and an electron-injection layer **915** which are included in an EL layer **902** are sequentially formed by a vacuum evaporation method.

The pressure in the vacuum evaporation apparatus was reduced to 1×10^{-4} Pa Pa. Then, 3-[4-(9-Phenanthryl)-phenyl]-9-phenyl-9H-carbazole (abbreviation: PCPPn) and molybdenum oxide were deposited by co-evaporation with a mass ratio of PCPPn to molybdenum oxide being 4:2, thereby forming the first hole-injection layer **911** on the first electrode **901**. A thickness thereof was set to be 10 nm. Note that a co-evaporation method is an evaporation method in which a plurality of different substances is concurrently vaporized from respective different evaporation sources.

Next, PCPPn was deposited to a thickness of 20 nm by evaporation, thereby forming the hole-transport layer **912**.

Next, the light-emitting layer **913** was formed on the hole-transport layer **912**.

In the case of Light-emitting element **1**, the light-emitting layer **913** was formed to a thickness of 25 nm by evaporation of 1,5CzP2A.

In the case of Light-emitting element **2**, 1,5CzP2A and 1,6mMemFLPAPrn that was a dopant (a light-emitting substance) were deposited by co-evaporation so that the mass ratio of 1,5CzP2A and 1,6mMemFLPAPrn was 1:0.03, whereby the light-emitting layer **913** was formed to a thickness of 25 nm.

In the case of Light-emitting element **3**, the light-emitting layer **913** was formed to a thickness of 25 nm by evaporation of 1,8CzP2A.

In the case of Light-emitting element **4**, 1,8CzP2A and 1,6mMemFLPAPrn that was a dopant (a light-emitting substance) were deposited by co-evaporation so that the mass ratio of 1,8CzP2A and 1,6mMemFLPAPrn was 1:0.03, whereby the light-emitting layer **913** was formed to a thickness of 25 nm.

Next, over the light-emitting layer **913**, 2,2'-(pyridine-2,6-diy)bis(4,6-diphenylpyrimidine) (abbreviation: 2,6 (P2Pm)2Py) was deposited to a thickness of 25 nm as the electron-transport layer **914**.

Furthermore, lithium fluoride was deposited by evaporation to a thickness of 1 nm over the electron-transport layer **914**, whereby the electron-injection layer **915** was formed.

Lastly, aluminum was deposited to a thickness of 200 nm over the electron-injection layer **915**, whereby a second electrode **903** serving as a cathode was formed. Thus, Light-emitting elements **2** and **4** were fabricated. It is to be noted that an evaporation method using resistive heating was employed for all the evaporation steps.

Table 1 shows element structures of Light-emitting elements **1** to **4** obtained by the above steps.

TABLE 1

	First electrode	Hole-injection layer	Hole-transport layer	Light-emitting layer	Electron-transport layer	Electron-injection layer	Second electrode
Light-emitting element 1	ITO (70 nm)	PCPPn:MoO*x* (4:2 10 nm)	PCPPn (20 nm)	1,5CzPA	2,6(P2Pm) 2Py (25 nm)	LiF (1 nm)	Al (200 nm)

TABLE 1-continued

	First electrode	Hole-injection layer	Hole-transport layer	Light-emitting layer	Electron-transport layer	Electron-injection layer	Second electrode
Light-emitting element 2				*			
Light-emitting element 3				1,8CzPA			
Light-emitting element 4				**			

* 1,5CzPA: 1,6mMemFLPAPrn (1:0.03 25 nm)
** 1,8CzPA: 1,6mMemFLPAPrn (1:0.03 25 nm)

The fabricated Light-emitting elements **1** to **4** were sealed in a glove box under a nitrogen atmosphere so as not to be exposed to the air (a sealant was applied to surround the elements, and at the time of sealing, UV treatment was performed and heat treatment was performed at 80° C. for 1 hour).

<Delayed Fluorescence Measurement of Light-Emitting Element>

Delayed fluorescence measurement was performed on Light-emitting elements **1** to **4**. A picosecond fluorescence lifetime measurement system (manufactured by Hamamatsu Photonics K.K.) was used for the measurement. To measure the lifetimes of fluorescence obtained from the light-emitting layers of Light-emitting elements **1** to **4**, the light-emitting elements were made to emit light by applying a square wave pulse voltage, and time-resolved measurements of light, which was attenuated from the falling of the voltage, were performed using a streak camera. The pulse voltage was applied at a frequency of 10 Hz. By integrating data obtained by repeated measurements, data with a high S/N ratio was obtained. The measurement was performed at room temperature (in an atmosphere kept at 23° C.) under the conditions of a pulse voltage of approximately 3 V, a pulse time width of 100 μsec, a negative bias voltage of −5 V, and a measurement time of 50 μsec.

The attenuation curves obtained by the measurement are shown in FIG. **19**. In FIG. **19**, the horizontal axis indicates the emission time (μs) elapsed after the falling of the pulse voltage and the vertical axis indicates the relative emission intensity (arbitrary unit). Fitting of the attenuation curves shown in FIG. **19** was performed using Formula (5).

$$L = \sum_{n=1} A_n \exp\left(-\frac{t}{a_n}\right) \tag{5}$$

In Formula (5), L and t represent normalized emission intensity and elapsed time, respectively.

As the results of the fitting of attenuation curves in FIG. **19**, the fitting was able to be performed when n was 1 and 2 in Formula (5). The fitting of the attenuation curves was performed and the proportion of the delayed fluorescence component in the total emission obtained from each of Light-emitting elements **1** to **4** was calculated by extrapolation of the fitting curves to t=0. As a result, the proportions of the delayed fluorescence component in the total emission obtained from Light-emitting element **1**, Light-emitting element **2**, Light-emitting element **3**, and Light-emitting element **4** were calculated to be 33%, 22%, 10%, and 6%, respectively. In other words, 5% or more of the delayed fluorescence component was observed in each of the Light-emitting elements **1** to **4**.

Light-emitting element **1** and Light-emitting element **2** included 1,5CzP2A in the respective light-emitting layers, and Light-emitting element **3** and Light-emitting element **4** included 1,8CzP2A in the respective light-emitting layers. That is, it was found that the proportion of the delayed fluorescence component in each of Light-emitting element **1** and Light-emitting element **2** including 1,5CzP2A in its light-emitting layer was higher than that of the delayed fluorescence component in each of Light-emitting element **3** and Light-emitting element **4** including 1,8 CzP2A in its light-emitting layer.

Note that a high proportion (specifically, 15% or more) of delayed fluorescence components in Light-emitting element **1** and Light-emitting element **3** indicates that in 1,5CzP2A and 1,8CzP2A which are the organic compounds, energy transfer from triplet excitons to singlet excitons occurs at a relatively high probability and that probability of TTA is increased. Specifically, by using 1,5CzP2A having a particularly high proportion of delayed fluorescence components in the light-emitting layer, the light-emitting element with high probability of TTA was obtained. Note that this result agrees with the result in Embodiment 1 in which 1,5CzP2A having a larger oscillator strength (f) than that in 1,8CzP2A when comparison is performed using the oscillator strength (f), has a higher probability of TTA.

<<Operation Characteristics of Light-Emitting Elements **1** to **4**>>

Operation characteristics of Light-emitting element **1** and Light-emitting element **3** in which dopant (a light-emitting substance) was not included in the respective light-emitting layers, and Light-emitting element **2** and Light-emitting element **4** in which dopant (a light-emitting substance) was included in the respective light-emitting layers were measured. It is to be noted that the measurements were performed at room temperature (in an atmosphere kept at 25° C.).

FIG. **20** shows current density-luminance characteristics of Light-emitting element **1** and Light-emitting element **3** in which dopant (a light-emitting substance) was not included in the respective light-emitting layers. FIG. **21** shows voltage-luminance characteristics thereof. FIG. **22** shows luminance-current efficiency characteristics thereof. FIG. **23** shows voltage-current characteristics thereof.

Table 2 shows initial values of main characteristics of Light-emitting element **1** and Light-emitting element **3** at a luminance of about 1000 cd/m^2.

TABLE 2

	Voltage (V)	Current (mA)	Current density (mA/cm^2)	Chromaticity (x, y)	Luminance (cd/m^2)	Current density (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting elemet 1	4.4	1.1	27	(0.15, 0.13)	760	2.8	2.0	2.6
Light-emitting element 3	5.4	1.5	37	(0.15, 0.11)	1000	2.7	1.6	2.8

FIG. **24** shows current density-luminance characteristics of Light-emitting elements **2** and **4**, FIG. **25** shows voltage-luminance characteristics thereof, FIG. **26** shows luminance-current efficiency characteristics thereof, and FIG. **27** shows voltage-current characteristics thereof.

Table 4 shows initial values of main characteristics of Light-emitting elements **2** and **3** at a luminance of approximately 1000 cd/m^2.

TABLE 3

	Voltage (V)	Current (mA)	Current density (mA/cm^2)	Chromaticity (x, y)	Luminance (cd/m^2)	Current density (cd/A)	Power efficiency (lm/W)	External quantum efficiency (%)
Light-emitting elemet 2	4.0	0.41	10	(0.14, 0.15)	800	7.8	6.1	7.0
Light-emitting element 4	5.0	0.60	15	(0.14, 0.16)	1100	7.6	4.8	6.5

When the external quantum efficiencies of Light-emitting elements **2** and **4** containing dopant (here, 1,6mMemFLPA-Prn) are compared with each other, Light-emitting element **2** in which 1,5CzP2A was used as a host material used in the light-emitting layer of the light-emitting element had a higher external quantum efficiency than that of Light-emitting element **4**. This indicated that the use of the material (1,5CzP2A) having a larger oscillator strength (f) was one factor allowing easy occurrence of TTA.

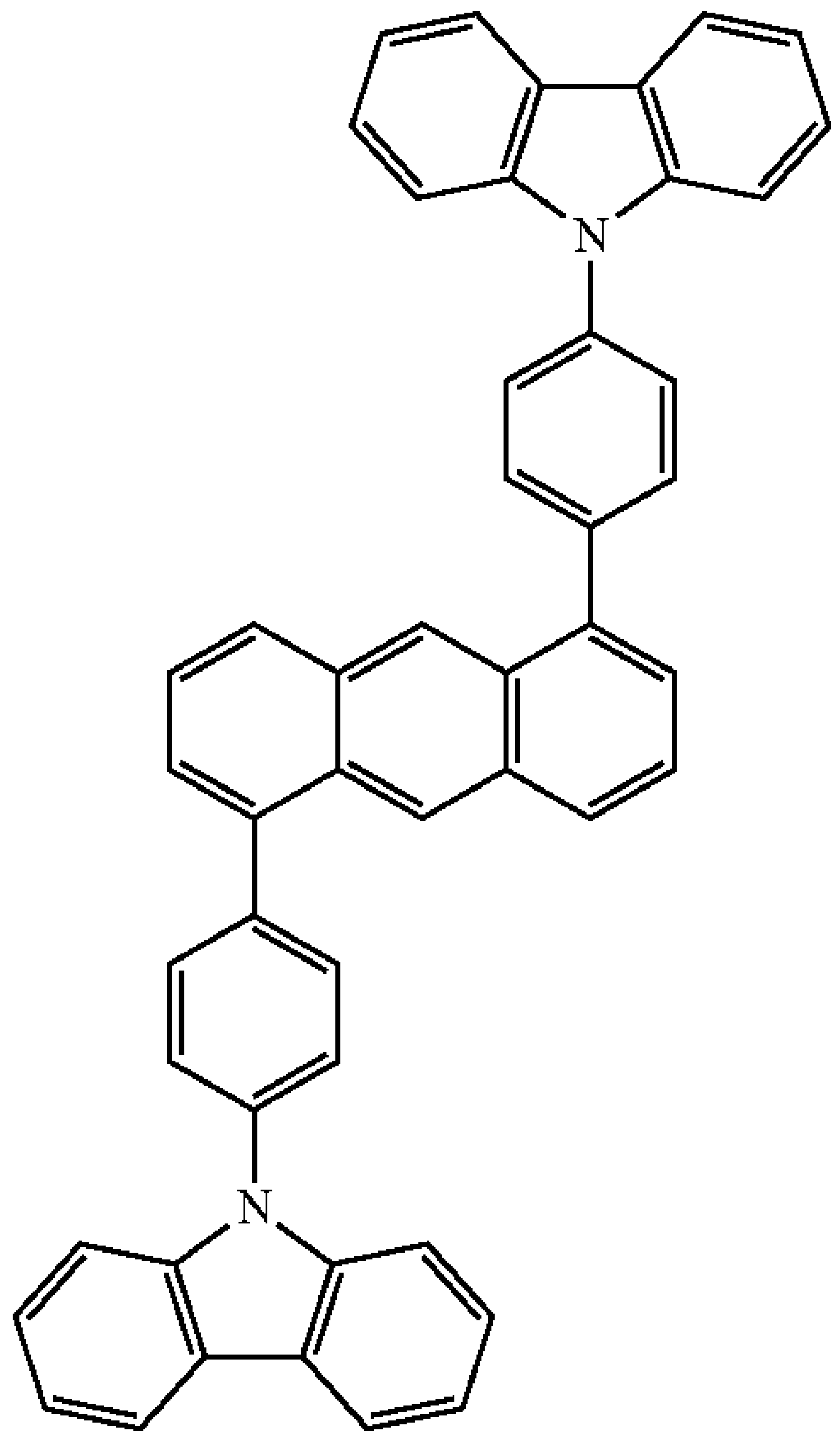
FIG. **28** shows emission spectra of Light-emitting elements **1** and **3** to which current was applied at a current density of 25 mA/cm^2. FIG. **29** shows an emission spectrum of Light-emitting elements **2** and **4**, to which current was applied at a current density of 25 mA/cm^2.

Example 2

Synthesis Example 1

In this example, a synthesis example of an organic compound, 1,5-bis[4-(9H-carbazole-9-yl)phenyl]anthracene (abbreviation: 1,5CzP2A) (Structural Formula:100) is described. Note that chemical formula of 1,5CzP2A is shown below.

(100)



1,5CzP2A

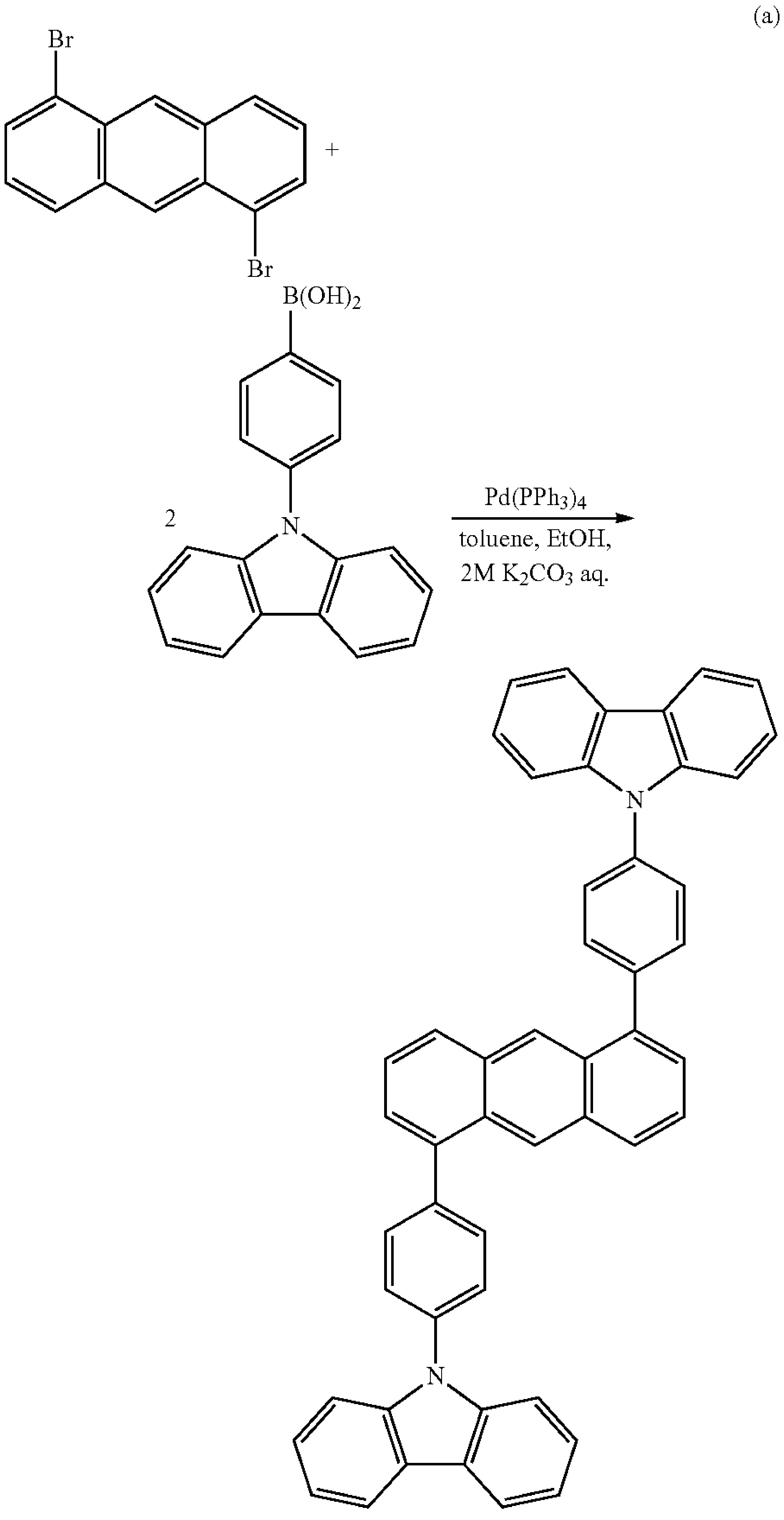
<Synthesis of 1,5CzP2A>

A mixture of 1.2 g (3.6 mmol) of dibromoanthracene, 2.3 g (7.9 mmol) of 4-(9H-carbazol-9-yl)phenylboronic acid, 2.2 g (16 mmol) of potassium carbonate, 30 mL of toluene, and 10 mL of ethanol, 8 mL of water, and 83 mg (71 μmol of tetrakis(triphenylphosphine)palladium(0) was stirred under a nitrogen stream at 90° C. for 14 hours.

After the stirring, the mixture was filtered, the obtained solid was washed with water and ethanol and then collected. This solid was purified by silica gel column chromatography (developing solvent: toluene). The purified solid was recrystallized, so that 2.0 g of a pale yellow solid was obtained in a yield of 86%.

The 2.0 g of obtained solid was purified by a train sublimation method under a pressure of 2.7 Pa in an argon stream at 343° C. After the purification, 1.8 g of a pale yellow solid was obtained at a collection rate of 90%. Synthesis scheme (a) of the above synthesis method is shown below.

(a)



1,5CzP2A
(100)

The following shows analysis results by nuclear magnetic resonance (^{1}H-NMR) spectroscopy of the pale yellow solid obtained by the above-described synthesis method. A ^{1}H-NMR chart is shown in FIGS. **30**A and **30**B. The ^{1}H NMR charts revealed that 1,5CzP2A, the organic compound of one embodiment of the present invention represented by Structural Formula (100), was obtained in Synthesis Example 1.

^{1}H-NMR ($CDCl_3$, 300 MHz): δ=7.36 (t, J_1=7.8 Hz, 4H), 7.51 (t, J_1=8.4 Hz, 4H), 7.57 (s, 2H), 7.58 (dd, J_1=6.9 Hz, J_2=11.7 Hz, 2H), 7.65 (d, J_1=7.8 Hz, 4H), 7.80 (d, J_1=8.4 Hz, 4H), 7.88 (d, J_1=8.7 Hz, 4H), 8.07 (dd, J_1=2.4 Hz, J_2=6.6 Hz, 2H), 8.22 (dd, J_1=7.5H, 4H), 8.72 (s=2H).

Next, ultraviolet-visible absorption spectra (hereinafter simply referred to as "absorption spectra") and emission spectra of 1,5CzP2A in a toluene solution and 1,5CzP2A in a solid thin film were measured. The solid thin film was formed over a quartz substrate by a vacuum evaporation method. The absorption spectra were measured using an ultraviolet-visible light spectrophotometer (V-550 type manufactured by JASCO Corporation). The emission spectra were measured using a fluorescence spectrophotometer (FS920 manufactured by Hamamatsu Photonics K.K.). FIG. **31**A shows the obtained absorption and emission spectra of 1,5CzP2A in the toluene solution. The horizontal axis represents wavelength, and the vertical axis represents absorption intensity. FIG. **31**B shows the obtained absorption and emission spectra of 1,5CzP2A in the solid thin film. The horizontal axis represents wavelength, and the vertical axis represents absorption intensity. The absorption spectrum shown in FIG. **31**A is a result obtained by subtraction of an absorption spectrum of toluene only put in a quartz cell from the measured absorption spectrum of the toluene solution in a quartz cell. The absorption spectrum of the thin film in FIG. **31**B was obtained by subtraction of an absorption spectrum of the quartz substrate from an absorption spectrum of the quartz on which 1,5CzP2A was deposited.

FIG. **31**A shows that 1,5CzP2A in the toluene solution has absorption peaks at around 287 nm, 293 nm, 327 nm, 341 nm, 359 nm, 378 nm, and 397 nm, and emission wavelength peaks at around 425 nm and 448 nm. (The excitation wavelength: 379 nm). FIG. **31**B shows that 1,5CzP2A in the solid thin film has absorption peaks at around 265 nm, 286 nm, 296 nm, 314 nm, 331 nm, 345 nm, 369 nm, 387 nm, and 404 nm, and an emission wavelength peak at around 462 nm. (The excitation wavelength: 345 nm).

Next, LC/MS analysis was performed. FIG. **32** shows the measurement results.

In the LC/MS analysis, liquid chromatography (LC) separation was carried out with ACQUITY UPLC® (manufactured by Waters Corporation) and mass spectrometry (MS) analysis was carried out with Xevo G2 Tof MS (manufactured by Waters Corporation).

For the LC separation, Acquity UPLC BEH C8 (2.1×100 mm, 1.7 μm) was used as a column, and a mixed solution of acetonitrile and a 0.1% formic acid aqueous solution was used for a mobile phase.

In the MS analysis, ionization was carried out by an electrospray ionization (ESI) method, and the analysis was performed in a positive mode. A component that underwent the ionization was collided with an argon gas in a collision cell to dissociate into product ions. Energy (collision energy) for the collision with argon was 50 eV. The mass range for the measurement was m/z=100 to 1200.

The result shows that precursor ions of 1,5CzP2A were detected around m/z=661, and product ions of 1,5CzP2A were detected around m/z=495 and m/z=707. These results are characteristically derived from 1,5CzP2A and thus can be regarded as important data in identification of 1,5CzP2A contained in the mixture.

Note that the product ion around m/z=495 is presumed to be a hydrogen ion adduct of a radical expressed as

$C_{38}H_{25}N.^{+}$ in the state where one carbazole is dissociated, and the product ion around m/z=707 is presumed to be acetonitrile and a hydrogen ion adduct. These indicate that a terminal of 1,5CzP2A has a carbazole skeleton and that acetonitrile is easily added. Note that acetonitrile was used for sample adjustment at the time of the analysis and for the mobile phase. Note that there is a possibility that the above m/z values±1 are detected as protonation or deprotonation products of the product ions.

Note that the synthesis method of 1,5CzP2A which is the organic compound of one embodiment of the present invention described in this example is a preferable example; however, the present invention is not limited to this example and another synthesis method can be employed.

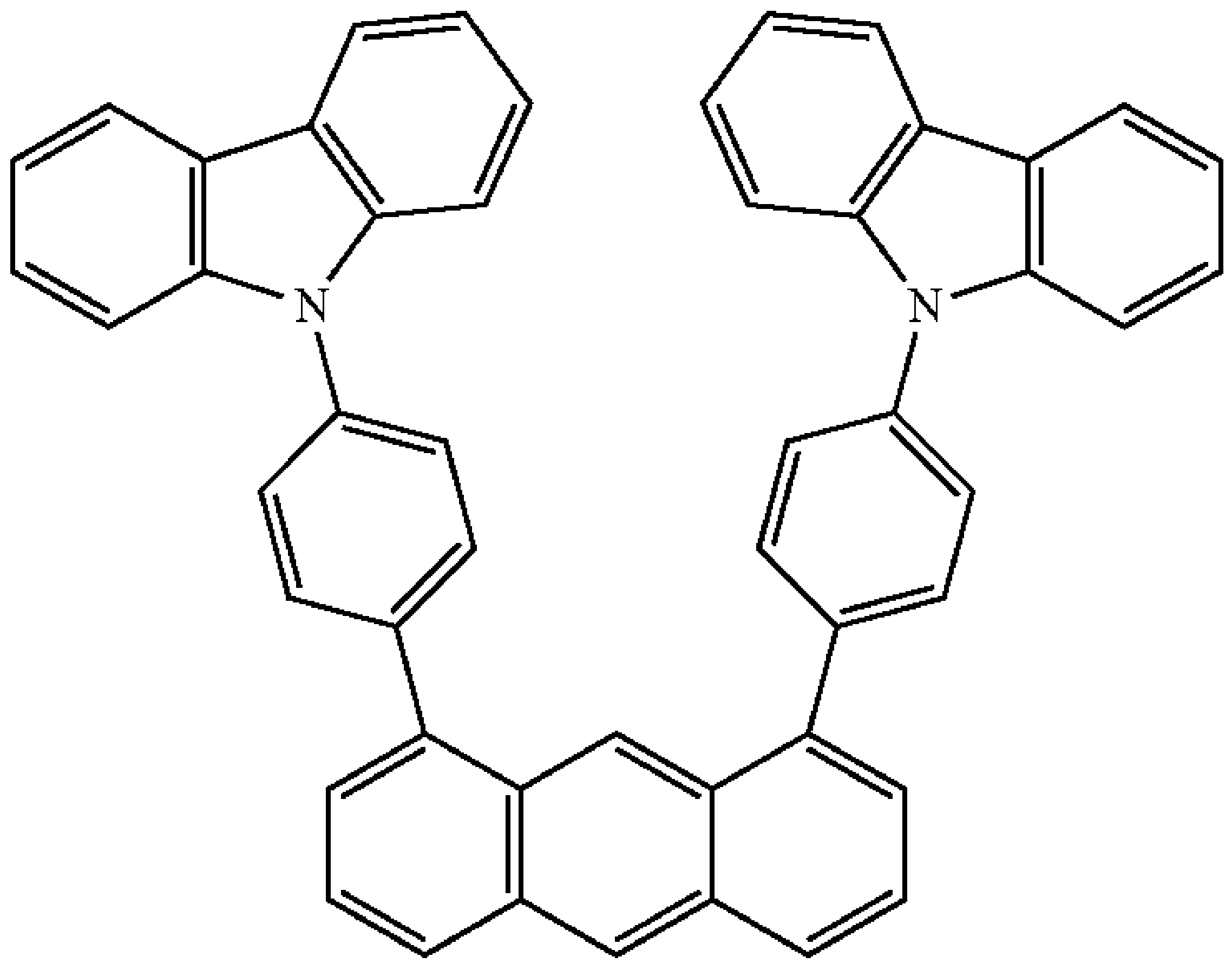
The above-described organic compound, 1,5CzP2A can be used not only as a host material of the light-emitting layer but also as a light-emitting substance.

Example 3

Synthesis Example 2

In this example, a synthesis method of an organic compound, 1,8-bis[4-(9H-carbazole-9-yl)phenyl]anthracene (abbreviation: 1,8CzP2A) is described. Note that chemical formula of 1,8CzP2A is shown below.

(110)



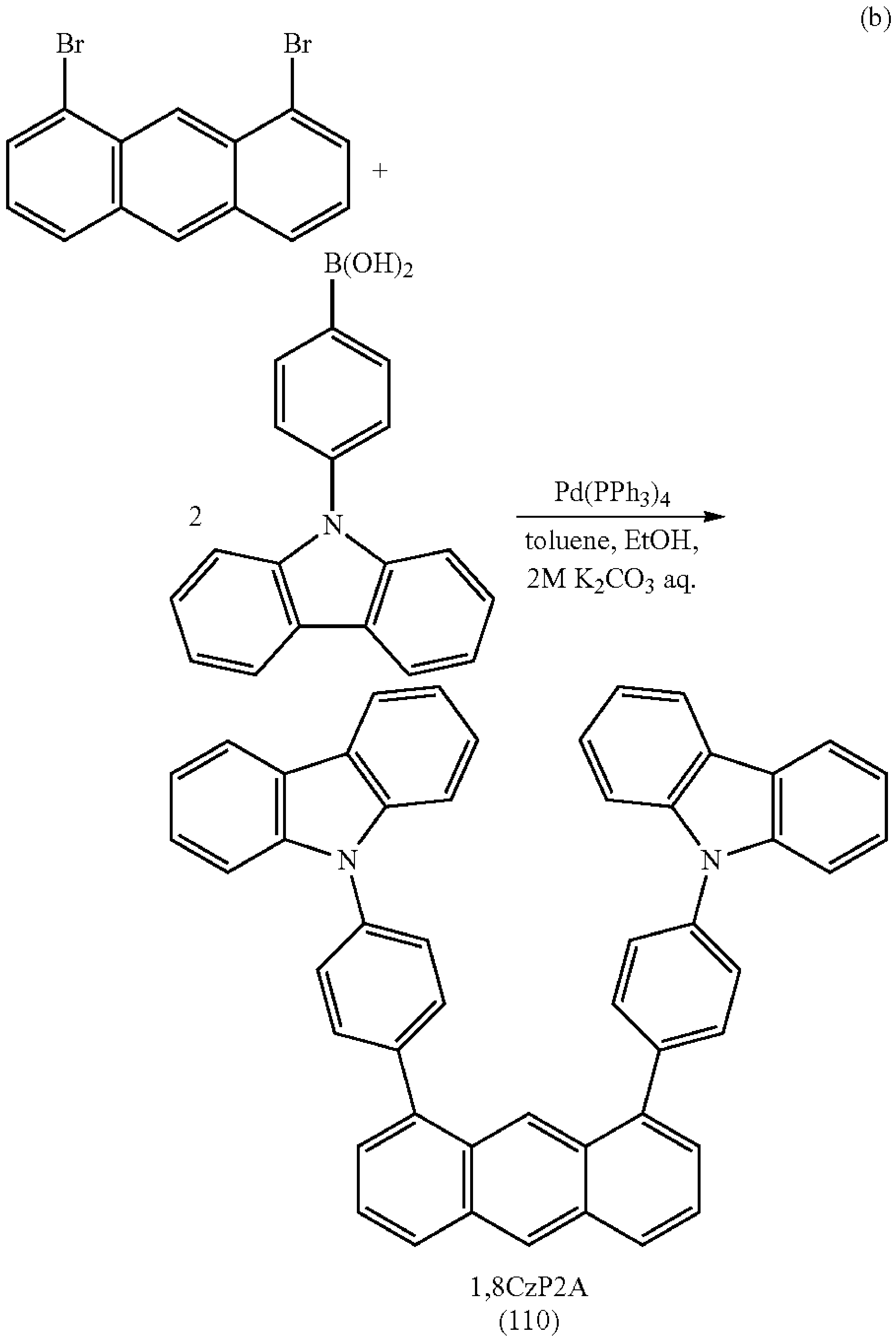
1,8CzP2A

<Synthesis of 1,8CzP2A>

In a 200 mL three-neck flask, a mixture of 1.2 g (3.7 mmol) of dibromoanthracene, 2.3 g (8.1 mmol) of 4-(9H-carbazol-9-yl)phenylboronic acid, 2.2 g (16 mmol) of potassium carbonate, 30 mL of toluene, and 10 mL of ethanol, 8 mL of water, and 85 mg (74 $_{1}$ μmol) of tetrakis(triphenylphosphine)palladium(0) was stirred under a nitrogen stream at 90° C. for 14 hours.

After the stifling, the mixture was filtered, the obtained solid was washed with water and ethanol and then collected. This solid was purified by silica gel column chromatography (developing solvent: toluene). The purified solid was recrystallized by toluene, so that 2.3 g of a pale yellow solid was obtained in a yield of 93%. 2.0 g of the obtained solid was purified by a train sublimation method under a pressure of 2.7 Pa in an argon stream at 295° C. After the purification, 1.9 g of a pale yellow solid was obtained at a collection rate of 83%. Synthesis scheme (b) of the above synthesis method is shown below.

(b)



The following shows analysis results by nuclear magnetic resonance (^{1}H-NMR) spectroscopy of the pale yellow solid obtained by the above-described synthesis method. A ^{1}H-NMR chart is shown in FIGS. **33**A and **33**B. The ^{1}H-NMR charts revealed that 1,8CzP2A, the organic compound of one embodiment of the present invention represented by Structural Formula (110), was obtained in Synthesis Example 2.

^{1}H NMR ($CDCl_3$, 300 MHz): δ=6.88 (t, J_1=7.2 Hz, 4H), 7.08 (t, J_1=7.8 Hz, 4H), 7.31 (d, J_1=8.1 Hz, 4H), 7.55 (dd, J_1=1.5 Hz, J_2=6.9 Hz, 2H), 7.60-7.68 (m, 6H), 7.80 (d, J_1=8.1 Hz, 4H), 8.03 (d, J_1=7.8 Hz, 4H), 8.14 (d, J_1=7.8 Hz, 2H), 8.66 (s, 1H), 8.95 (s, 1H).

Next, ultraviolet-visible absorption spectra (hereinafter simply referred to as "absorption spectra") and emission spectra of 1,8CzP2A in a toluene solution and 1,8CzP2A in a solid thin film were measured. The toluene solution and the solid thin film were each measured in a manner similar to that in Example 2. FIG. **34**A shows the obtained absorption and emission spectra of 1,8CzP2A in the toluene solution. The horizontal axis represents wavelength, and the vertical axis represents absorption intensity. FIG. **34**B shows the obtained absorption and emission spectra of the solid thin film. The horizontal axis represents wavelength, and the vertical axis represents absorption intensity.

FIG. **34**A shows that 1,8CzP2A in the toluene solution has absorption peaks at around 287 nm, 294 nm, 328 nm, 341 nm, 361 nm, 380 nm, and 399 nm, and emission wavelength peaks at around 423 nm and 445 nm. (The excitation wavelength: 381 nm). FIG. **34**B shows that 1,8CzP2A in the solid thin film has absorption peaks at around 265 nm, 286 nm, 296 nm, 315 nm, 331 nm, 344 nm, 370 nm, 388 nm, and 404 nm, and an emission wavelength peak at around 468 nm. (The excitation wavelength: 345 nm).

Next, LC/MS analysis was performed. The measurement method was similar to that used in Example 2. FIG. **35** shows the measurement results.

The result shows that precursor ions of 1,8CzP2A were detected around m/z=661, and product ions of 1,8CzP2A were detected around m/z=243, m/z=329, and m/z=495. The results are characteristically derived from 1,8CzP2A and thus can be regarded as important data in identification of 1,8CzP2A contained in a mixture.

Note that the product ion around m/z=243 is presumed to be a proton adduct of a radical of phenylcarbazole expressed as $C_{18}H_{13}N.^{+}$; the product ion around m/z=329 is presumed to be a hydrogen ion adduct of a biradical expressed as $C_{26}H_{172}.^{+}$ in the state where two carbazoles are dissociated; and the product ion around m/z=495 is presumed to be a hydrogen ion adduct of a radical expressed as $C_{38}H_{25}.^{+}$ in the state where one carbazole is dissociated. These indicate that a terminal of 1,8CzP2A includes two carbazole skeletons and a phenylcarbazole skeleton. Note that there is a possibility that the above m/z values±1 are detected as protonation or deprotonation products of the product ions.

Note that the synthesis method of 1,8CzP2A which is the organic compound of one embodiment of the present invention described in this example is a preferable example; however, the present invention is not limited to this example and another synthesis method can be employed.

The above-described organic compound, 1,8CzP2A can be used as not only as a host material of the light-emitting layer but also as a light-emitting substance.

This application is based on Japanese Patent Application serial no. 2015-146604 filed with Japan Patent Office on Jul. 24, 2015 and Japanese Patent Application serial no. 2016-006140 filed with Japan Patent Office on Jan. 15, 2016, the entire contents of which are hereby incorporated by reference.

What is claimed is:

1. A light-emitting element comprising:

an EL layer between an anode and a cathode,

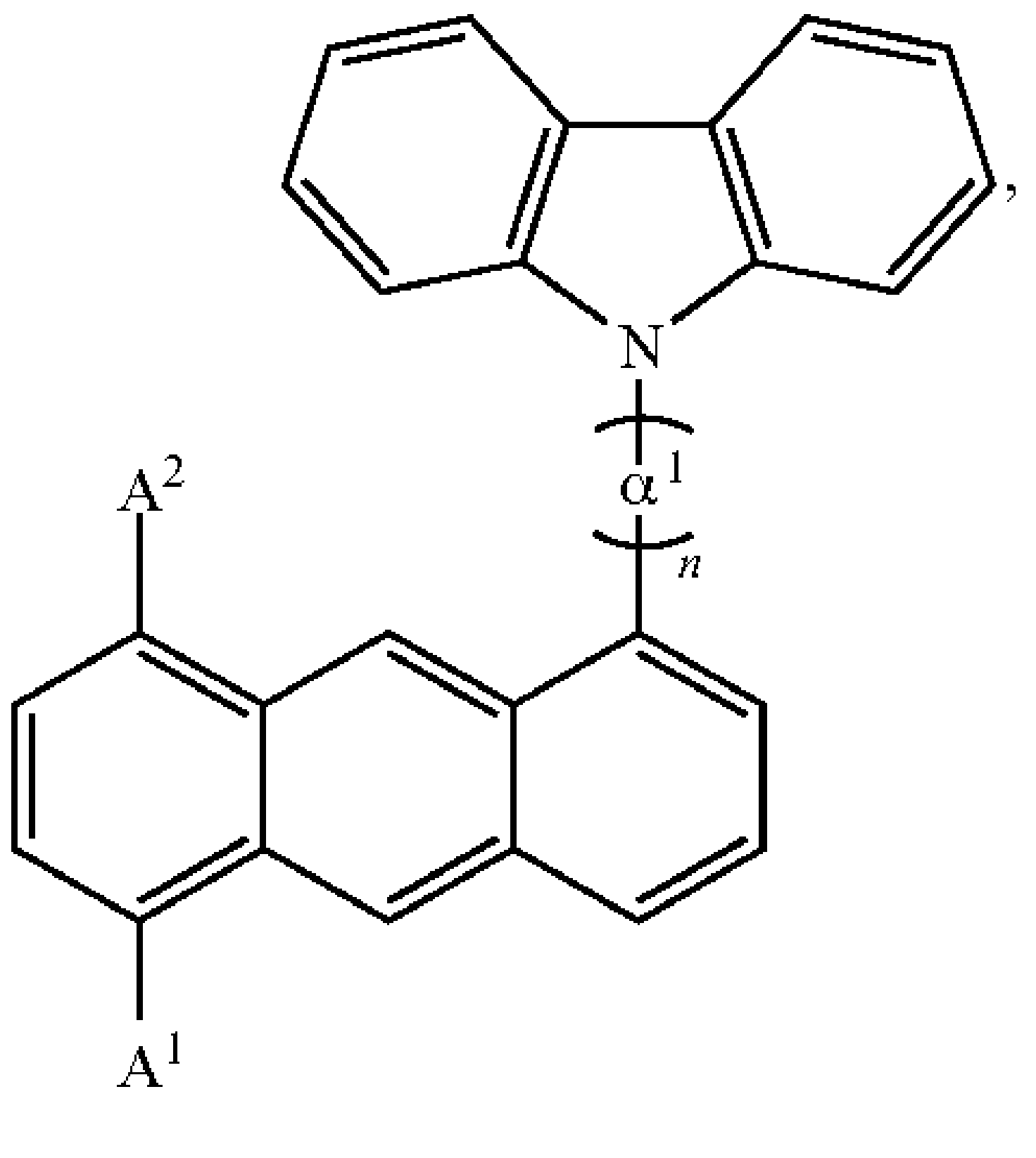
wherein the EL layer includes a light-emitting layer,

wherein the light-emitting layer includes a first organic compound,

wherein a difference between a T_1 level of the first organic compound and one or more of T_n levels of the first organic compound is less than the sum of the T_1 level and 0.6 eV,

wherein the first organic compound has a structure represented by General Formula (G1)

(G1)

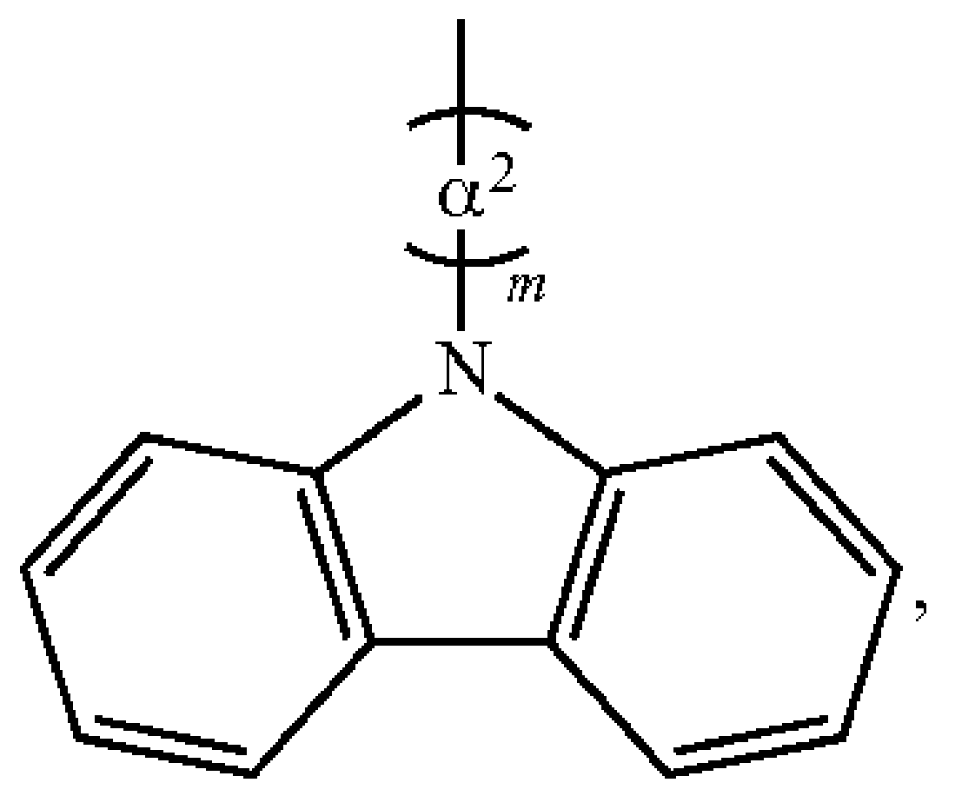


wherein α^1 represents a substituted or unsubstituted phenylene group,

wherein n represents 1 or 2,

wherein one of A^1 and A^2 is a first substituent represented by General Formula (G1-1)

(G1-1)



wherein α^2 represents a substituted or unsubstituted phenylene group,

wherein m represents 1 or 2, and

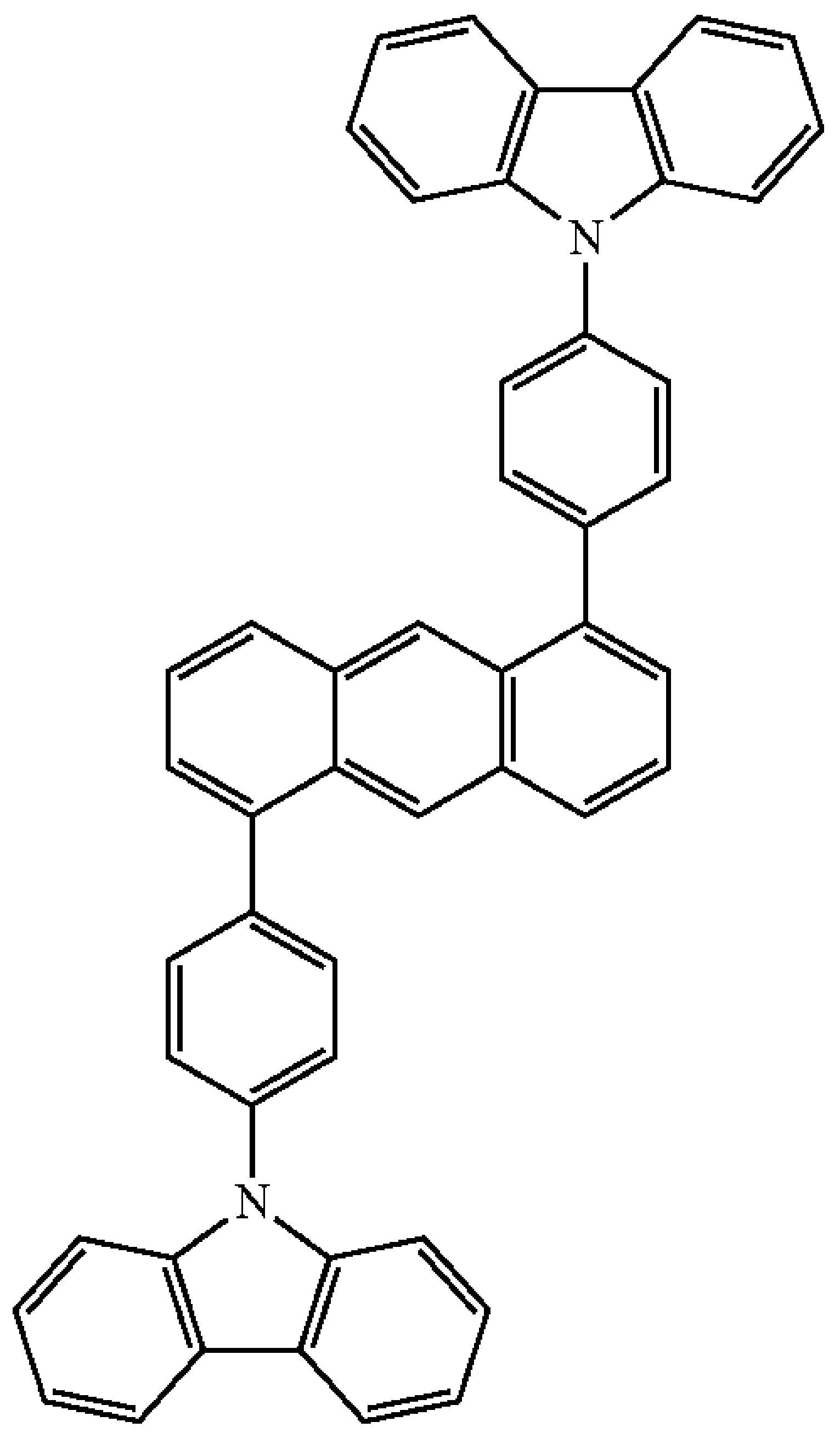
wherein the other of A^1 and A^2 is hydrogen or a second substituent different from the first substituent.

2. The light-emitting element according to claim **1**, wherein an energy difference between the one or more of T_n levels of the first organic compound and any one of an S_1 level and S_n levels of the first organic compound is 1 eV or less.

3. The light-emitting element according to claim **1**, wherein an oscillator strength for excitation from the T_1 level of the first organic compound to the one or more of T_n levels of the first organic compound is 0.0015 or more.

4. The light-emitting element according to claim **1**, wherein the first organic compound has Structural Formula (100) or Structural Formula (110).

(100)



1,5CzP2A

-continued

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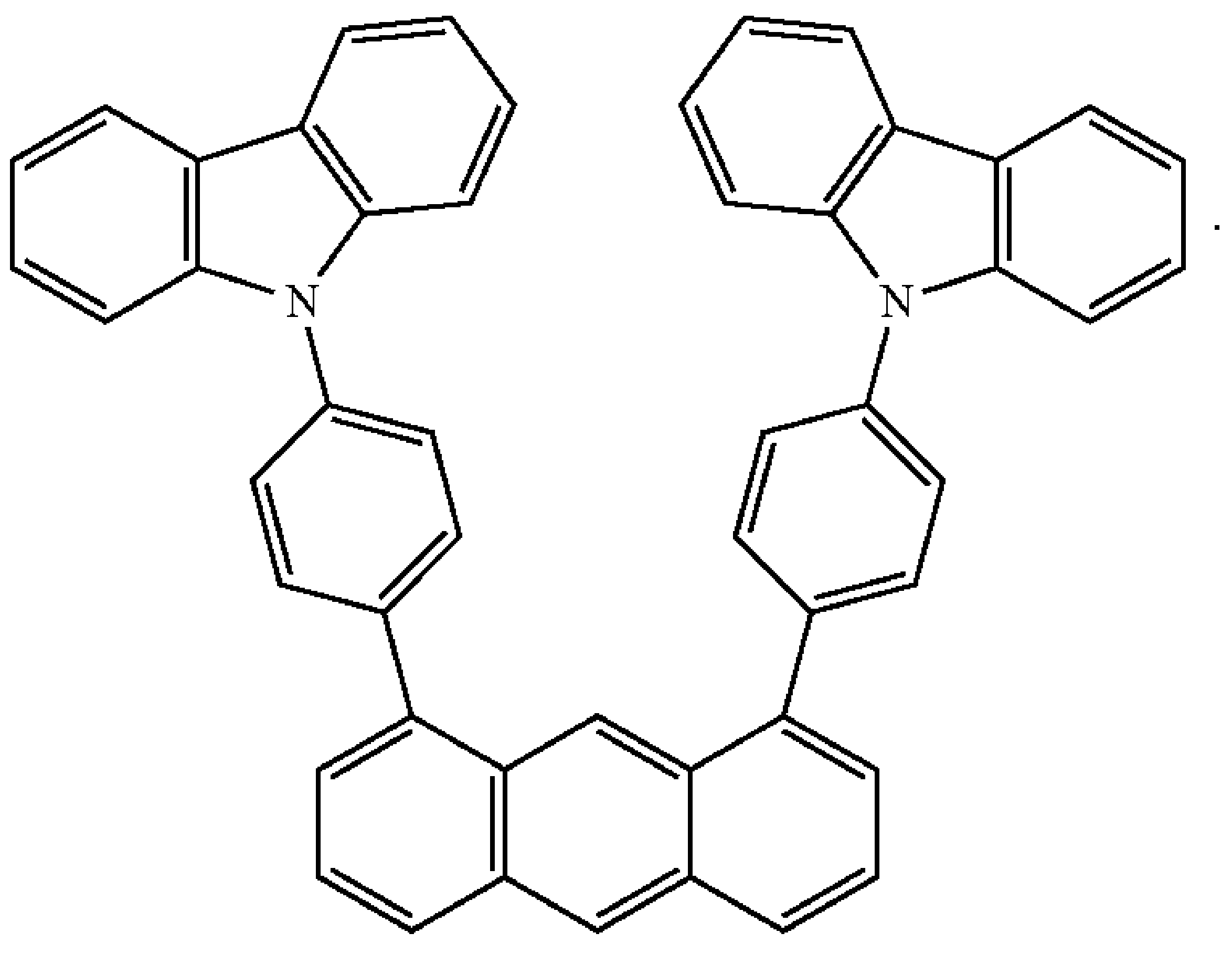


1,8CzP2A

5. The light-emitting element according to claim **1**,

wherein light emission from the light-emitting element includes a delayed fluorescence component, and

wherein an emission intensity of the delayed fluorescence component is 5% or more to that of a total amount of the light emission.

6. The light-emitting element according to claim **5**,

wherein the light-emitting layer further includes a second organic compound,

wherein an S_1 level of the first organic compound is higher an S_1 level of the second organic compound, and

wherein the light emission from the light-emitting element is derived from the second organic compound.

7. The light-emitting element according to claim **6**, wherein the second organic compound includes a pyrene skeleton.

8. The light-emitting element according to claim **6**, wherein a T_1 level of the second organic compound is higher than the T_1 level of the first organic compound.

9. The light-emitting element according to claim **6**,

wherein the EL layer further includes a hole-transport layer including a third organic compound,

wherein the hole-transport layer is located between the anode and the light-emitting layer and in contact with the light-emitting layer, and

wherein a T_1 level of the third organic compound included in the hole-transport layer is higher than the T_1 level of the first organic compound.

10. The light-emitting element according to claim **9**,

wherein the EL layer further includes an electron-transport layer including a fourth organic compound,

wherein the electron-transport layer is located between the cathode and the light-emitting layer and in contact with the light-emitting layer, and

wherein a T_1 level of the fourth organic compound included in the electron-transport layer is higher than the T_1 level of the first organic compound.

11. A light-emitting device comprising:

the light-emitting element according to claim **1**, and

one of a transistor and a substrate.

12. An electronic device comprising:

the light-emitting device according to claim **11**, and

any one of microphone, a camera, an operation button, an external connection portion, and a speaker.

13. An electronic device comprising:

the light-emitting device according to claim **11**, and

one of a housing and a touch sensor.

14. A lighting device comprising:

the light-emitting device according to claim **11**, and

any one of a housing, a cover, and a support.

15. A lighting system comprising:

a sensor;

a control unit electrically connected to the sensor; and

a light-emitting element electrically connected to the control unit,

wherein information acquired by the sensor is input to the control unit,

wherein the control unit is configured to drive the light-emitting element based on the information,

wherein the light-emitting element includes an EL layer between an anode and a cathode,

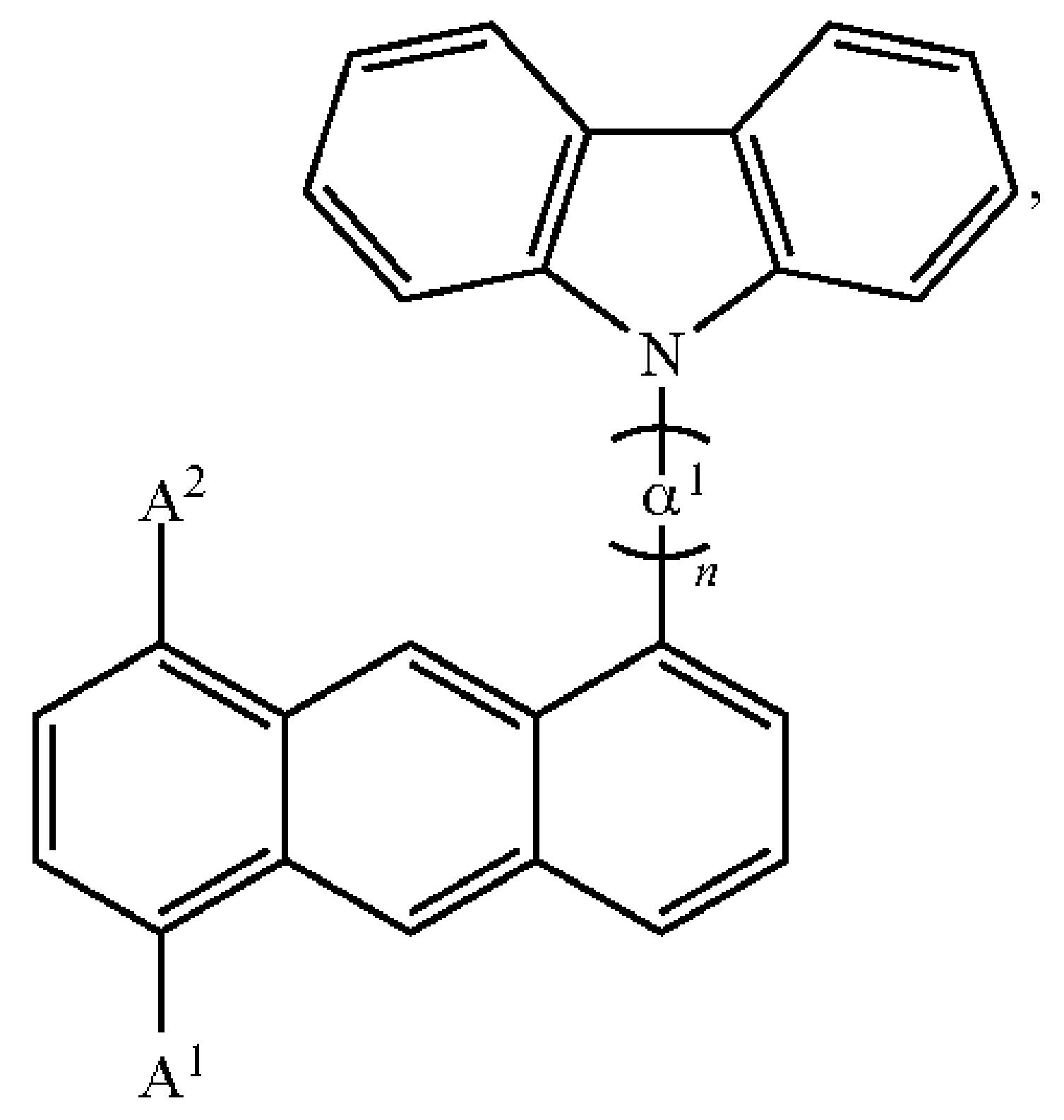
wherein the EL layer includes a light-emitting layer,

wherein the light-emitting layer includes a first organic compound,

wherein a difference between a T_1 level of the first organic compound and one or more of T_n levels of the first organic compound is less than the sum of the T_1 level and 0.6 eV,

wherein the first organic compound has a structure represented by General Formula (G1)

(G1)

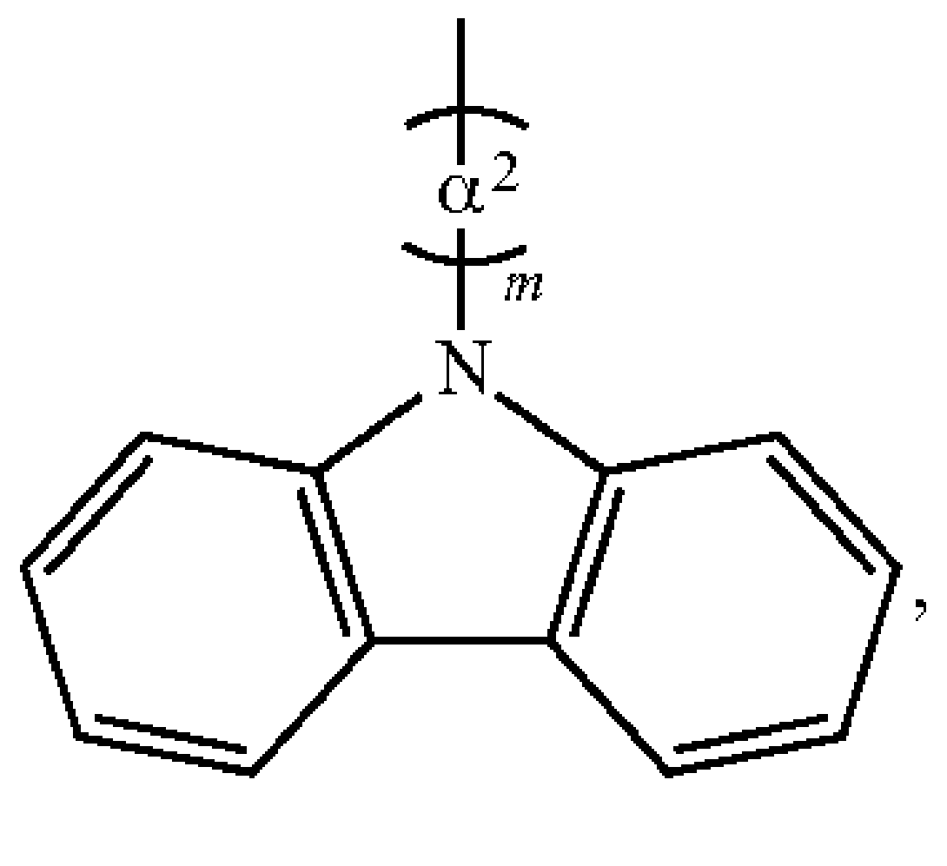


wherein α^1 represents a substituted or unsubstituted phenylene group,

wherein n represents 1 or 2,

wherein one of A^1 and A^2 is a first substituent represented by General Formula (G1-1)

(G1-1)



wherein α^2 represents a substituted or unsubstituted phenylene group,

wherein m represents 1 or 2, and

wherein the other of A^1 and A^2 is hydrogen or a second substituent different from the first substituent.

16. The lighting system according to claim **15**, wherein an energy difference between the one or more of T_n levels of the first organic compound and any one of an S_1 level and S_n levels of the first organic compound is 1 eV or less.

17. A lighting system comprising:

a sensor;

a control unit; and

a light-emitting element,

wherein the control unit includes a communication unit, a CPU, and a memory,

wherein the memory includes a program for driving the light-emitting element based on exterior information,

wherein the communication unit is configured to send the exterior information acquired by the sensor to the CPU,

wherein the CPU is configured to drive the light-emitting element by reading out the program from the memory and executing the program,

wherein the light-emitting element includes an EL layer between an anode and a cathode,

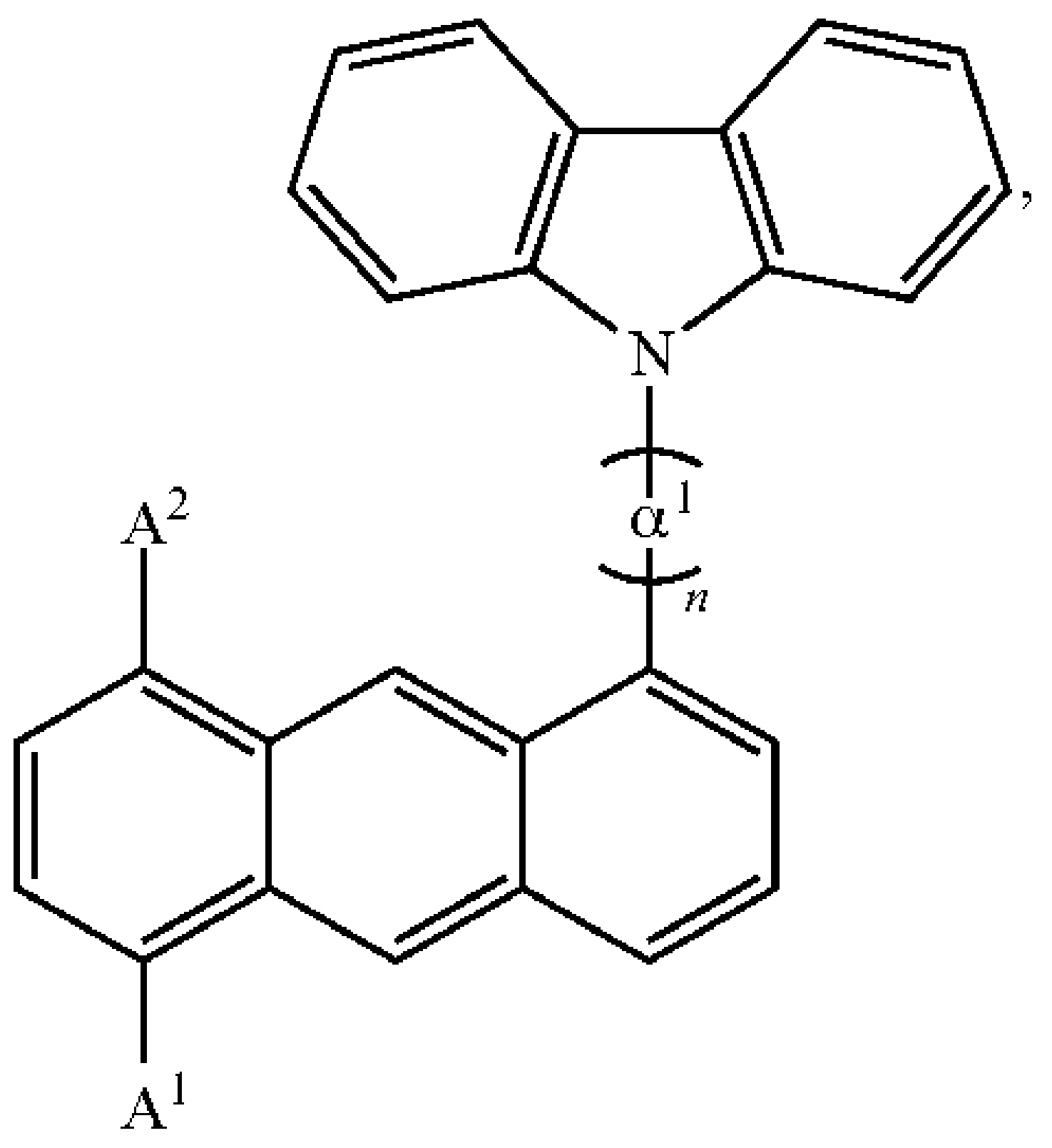
wherein the EL layer includes a light-emitting layer,

wherein the light-emitting layer includes a first organic compound,

wherein a difference between a T_1 level of the first organic compound and one or more of T_n levels of the first organic compound is less than the sum of the T_1 level and 0.6 eV,

wherein the first organic compound has a structure represented by General Formula (G1)

(G1)

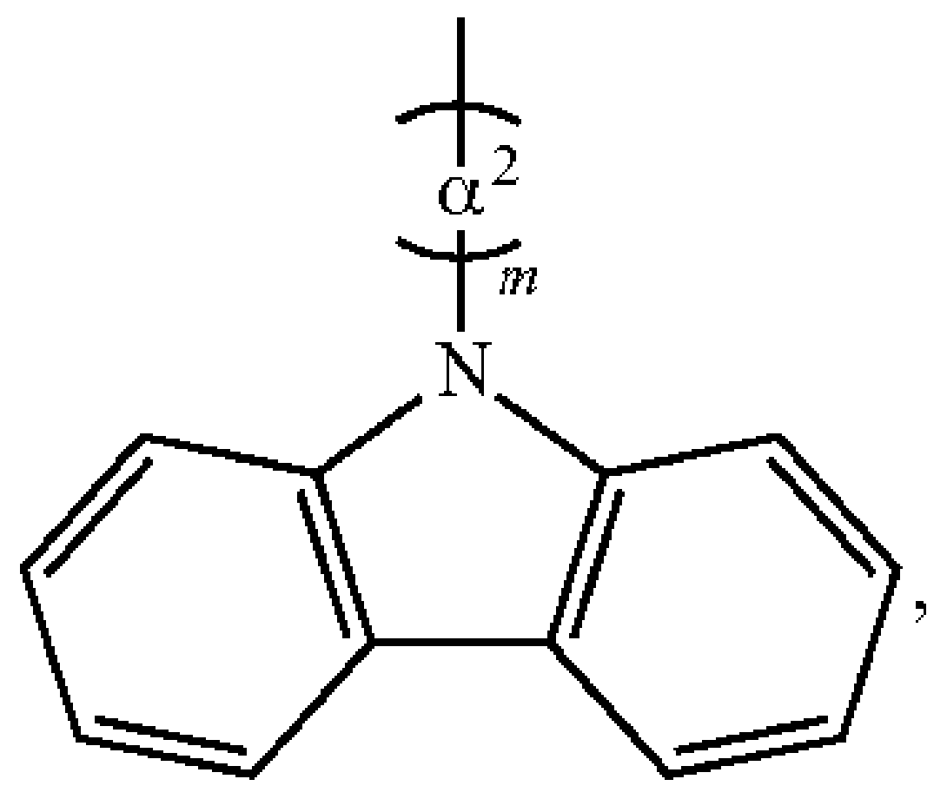


wherein α^1 represents a substituted or unsubstituted phenylene group,

wherein n represents 1 or 2,

wherein one of A^1 and A^2 is a first substituent represented by General Formula (G1-1)

(G1-1)



wherein α^2 represents a substituted or unsubstituted phenylene group,

wherein m represents 1 or 2, and

wherein the other of A^1 and A^2 is hydrogen or a second substituent different from the first substituent.

18. The lighting system according to claim **17**, wherein an energy difference between the one or more of T_n levels of the first organic compound and any one of an S_1 level and S_n levels of the first organic compound is 1 eV or less.

19. The light-emitting element according to claim **1**, wherein the second substituent includes at least one of an alkyl group having 1 to 6 carbon atoms, a cycloalkyl group having 1 to 6 carbon atoms, an alkylphenyl group, and a phenyl group.

20. The light-emitting element according to claim **1**, wherein, in General Formula (G1), A^1 is the first substituent represented by General Formula (G1-1) and A^2 is hydrogen or the second substituent.

21. The lighting system according to claim **15**, wherein the second substituent includes at least one of an alkyl group having 1 to 6 carbon atoms, a cycloalkyl group having 1 to 6 carbon atoms, an alkylphenyl group, and a phenyl group.

22. The lighting system according to claim **15**, wherein, in General Formula (G1), A^1 is the first substituent represented by General Formula (G1-1) and A^2 is hydrogen or the second substituent.

23. The lighting system according to claim **17**, wherein the second substituent includes at least one of an alkyl group having 1 to 6 carbon atoms, a cycloalkyl group having 1 to 6 carbon atoms, an alkylphenyl group, and a phenyl group.

24. The lighting system according to claim **17**, wherein, in General Formula (G1), A^1 is the first substituent represented by General Formula (G1-1) and A^2 is hydrogen or the second substituent.

* * * * *